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TWO EVALUATIVE MODELS FOR A FAMILY
OF SUBMARINE VERSUS SUBMARINE EXPANDING
SQUARE SEARCH PLANS

Thomas Joseph Smith

Naval Postgraduate School
Monterey, California

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Two Evaluative Models for a Family
of
Submarine Versus Submarine Expanding Square Search Plans

by

Thomas Joseph Smith
Lieutenant, United States Navy
B.S., College of the Holy Cross, 1966

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Author

Thomas Joseph Smith

Approved by:

Ken R. Wessburn Thesis Advisor

Dr. C. T. Lin Second Reader

Jack R. Bunting
Chairman, Department of Operations Research
and Administrative Sciences

M. Lloyd H. Clancy Academic Dean

ABSTRACT

This thesis investigates the effectiveness of a search plan developed by B. O. Koopman in a submarine versus submarine search situation. Two computer simulation models allow probability of target detection as a function of sonar range to be used as a measure of effectiveness. The Koopman search plan is analyzed and a family of alternate search plans are developed. The choice of a particular alternate search plan is dependent on the parameters of the problem. These parameters are target speed, searcher speed, time late to the search area and total time available to conduct the search. By use of the computer programs a search plan can be chosen so as to maximize the probability of target detection at a particular sonar range for each combination of input parameters.

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I. INTRODUCTION

During World War II a great deal of analytical and statistical work was done in the field of military operations. In particular the Navy benefited greatly from the work of the Operations Research Group (ORG) headed by Bernard O. Koopman. The Group's research has been compiled into a single volume entitled Search and Screening (OEG Report No. 56). This volume explores the application of the scientific method to tactical problems of naval warfare. It is intended to serve as a theoretical framework and foundation for more immediate practical studies. Philip M. Morse in the forward to Search and Screening (OEG Report No. 56) stated:

"Although the tactical doctrines presented apply to instruments, weapons and conditions prevailing during World War II, it is believed that the methods and systematic processes of analysis which led to the doctrines have wide application--not only to submarine warfare but to many other military and civilian problems."

The analysis performed and the tactical applications devised by the Operations Research Group have withstood the test of time very well. Although extensive progress has been made in the methods of operations research since World War II, many of the tactical applications derived by the Operations Research Group are still considered the best available by current practitioners of the art.

In particular the methods developed by Dr. J.M. Dobbie for constructing expanding square searches for targets in transit have been widely applied. However, some of these applications may be inappropriate. One use they

have been applied to is that of a submerged submarine searching for another submerged submarine. In this particular situation the use of the search plan developed by Koopman and Dobbie is questionable. This thesis will investigate the appropriateness of the Koopman search plan in the submarine versus submarine search situation.

II. DISCUSSION OF THE KOOPMAN SEARCH PLAN

A. BASIC ASSUMPTIONS OF THE KOOPMAN SEARCH PLAN

In planning a search the nature of the target is usually known. The general position of the target is usually a random variable. Unless a fairly accurate estimate of its motion can be made, the search plan will have to be designed so as to be effective against a target having any one of many different sorts of motion. This plan assumes that the target speed is known exactly and that the target's course is a constant. When the object of search has had its approximate location disclosed at a certain time, the searcher has the problem of disposing its subsequent searching effort (which is always limited) in such a manner as to maximize its chance of detecting the target. This is subject of course to the searcher's limitations and the practical limitations of navigation.

It is assumed that information regarding the point of fix is received by the searcher. The time of this position information is also assumed known. It is further assumed that the searcher is airborne and has a considerable speed advantage over the target.

The information concerning the target's position is not exact. Only a probability distribution of target positions is actually given. This distribution will have its greatest density at the point of fix and fall continuously to zero at a distance. The distribution will be assumed to be circular normal in form. Therefore, the probability that the target at the time of fix will be in a certain small region $dx dy$ at the point (x,y) a distance r from the origin (point of fix) is given by the following:

$$f(x,y) = f(r) = \frac{1}{2\pi\sigma^2} e^{-r^2/2\sigma^2}$$

where σ is the standard deviation of the circular normal distribution.

It is assumed that the target's speed is known. The target's course is unknown but is assumed to be distributed uniformly between zero and 360 degrees. The target location distribution at a particular time, T hours after the initial fix at a distance r from the origin (point of fix), can be expressed by the following probability density:

$$f(x,y;T) = f(r;T) = \frac{1}{2\pi\sigma^2} e^{-(r^2 + St^2 T^2)/2\sigma^2} I_0(\frac{St r T}{2})$$

The derivation of these relationships are shown in chapter two of Koopman [Ref. 1] where St is the estimated target speed. In this equation I_0 is the ordinary Besel function of zeroth order value for pure imaginary arguments of the function.

Figure 1 is a graph of $2\pi\sigma^2 f(r;T)$ this function plotted for various values of t as a function of r . It is obvious from figure one that when StT is greater than three sigma (3σ) the distribution has its maximum at $r = StT$.

Because of this a search plan can be constructed for large values of time which have elapsed from the time of fix to the time of initiation of the search. This time interval is called time late.

Theoretically the searcher should head for a position at a distance r where $r = StT$ from the point of fix. This will place him on the peak

of the target location distribution which is circular in form. The search pattern should then be constructed so as to maintain the searcher's position at the point of maximum density of the target location distribution. This would result in a search plan that resembled an equiangular or logarithmic spiral. There are practical considerations which make this infeasible, namely navigation problems and the undesirability of constant helming. Therefore, a search plan was constructed which approximates the theoretically optimal plan.

B. CONSTRUCTION OF THE KOOPMAN SEARCH PLAN

The theoretically optimal search plan was approximated by an expanding square search plan. Each circuit or square consists of four legs with 90 degree turns. The shape of the squares are shown in figure 2. The leg lengths are L_1 , L_2 , L_3 , etc., and the corresponding distances of the search legs from the point of fix are r_1 , r_2 , r_3 , etc. The time required for the searcher to go from point A to point B is $(r_1 + r_2)/S_0$, where S_0 is the searcher's speed. The time required for the target to move from a distance r_1 from the point of fix to a distance r_2 from the point of fix is $(r_2 - r_1)/S_t$ where S_t is the target speed. The searcher will just keep up with the target if these times are equal. By this reasoning

$$r_2 = mr_1$$

$$r_3 = mr_2$$

$$r_4 = mr_3$$

where

$$m = \frac{S_0 + S_t}{S_0 - S_t}$$

If we were to make $r_5 = mr_4$, the fifth leg would duplicate the position of the first leg in space relative to the target. That is to say that the searcher would be on the highest density point of the target location distribution. However, having traveled the first circuit (four legs) so as to be at this point of maximum density and not having detected the target has imparted additional information to the searcher. The first circuit being unsuccessful has altered the target location distribution. The target location distribution after one circuit is no longer unimodal. It is now a bimodal distribution with a depression where the peak of the initial target distribution function had been. This is caused by the fact that one circuit has been completed without detecting the target. Therefore, the second circuit should be flown either inside or outside the original peak. This will place the second circuit on one of the modal points of the new distribution. If the second circuit is constructed outside the peak, the third circuit should be constructed inside the peak, so as to be on the other modal value of the distribution.

In order to accomplish this objective the fifth leg was moved a distance S outside the position of the first leg in space relative to the target. This distance S is called the sweep spacing. A complete analytical development of an appropriate value for S is given in Ref. 1, chapter two and chapter seven. The final results of this development obtain the following form for the sweep spacing such that

$$S = 0.75 \sqrt{E} 6$$

where

$$E = W/2 \ln 2$$

W = sweep width

= 2 x Sonar Range

6 = the standard deviation of the circular normal distribution.

Therefore, r_5 is determined so that

$$\frac{r_5 + r_4}{s_0} = \frac{r_5 - r_4 - s}{st}$$

so that

$$r_5 = mr_4 + A$$

where

$$A = \frac{s_0 \times s}{\frac{s_0 - st}{s_0}}$$

A first approximation to r_1 is $st \times T$. However, the approximation to the spiral by straight search legs requires that r_1 be slightly less than this value. Therefore, a reasonable first approximation to r_1 is obtained by setting $r_1 = 0.9 \times st \times T$. Since any change in target course will reduce the outward component of velocity and since the second circuit is to be outside, the first r_1 was reduced further and taken so that

$$r_1 = 0.8 \times st \times T$$

Continuing we obtain the following:

$$r_2 = mr_1$$

$$r_3 = mr_2$$

$$r_4 = mr_3$$

$$r_5 = mr_4 + A$$

$$r_6 = mr_5$$

$$r_7 = mr_6$$

$$r_8 = mr_7$$

$$r_9 = mr_8 - 2A$$

$$r_{10} = mr_9$$

$$r_{11} = mr_{10}$$

$$r_{12} = mr_{11}$$

$$r_{13} = mr_{12} + 3A \text{ etc.}$$

Using the relationship between the lengths of the legs and their distances from the point of fix the following equations were obtained for the various search leg values:

$$L_1 = mr_1$$

$$L_2 = mL_1 + r_1$$

$$L_3 = mL_2$$

$$L_4 = mL_3 + A$$

$$L_5 = mL_4$$

$$L_6 = mL_5 + A$$

$$L_7 = mL_6$$

$$L_8 = mL_7 - 2A$$

$$L_9 = mL_8$$

$$L_{10} = mL_9 - 2A$$

$$L_{11} = mL_{10}$$

$$L_{12} = mL_{11} + 3A \text{ etc.}$$

This search plan was developed for large values of T where it was true that the maximum point of the distribution was located at a distance $r = StT$. The question arises as to what is the smallest value of T for which this search plan may be used for all values of T larger

than this lower bound without any essential decrease in the probability of detection for a given amount of search effort. By observing figure 1 it is seen that when T is less than $6/St$ the distribution resembles the original circular normal distribution. For T larger than $26/St$ the distribution has its maximum at approximately $r = St \times T$ and moves outward at St the speed of the target. However, there is a very rapid change in the distribution as T increases from $6/St$ to $26/St$. This change of the distribution from a stationary distribution to a distribution moving at the speed of the target makes the decision on a lower bound for T most difficult. Koopman and his associates, by an empirical method of testing the search plan against various values of T , concluded that a reasonable lower bound on T was $6/St$. Therefore, for values of $T \geq 6/St$ this search plan was considered optimal by Koopman and Dobbie. For values of $T < 6/St$ the plan for large values of T is sufficient and may be used.

C. ANALYSIS OF THE KOOPMAN SEARCH PLAN

It is necessary to evaluate the assumptions used in constructing the Koopman search plan when applied to its use by a submerged submarine searching for another submerged submarine. The assumptions of constant detectability over time and detectability being independent of target aspect are acceptable for the submarine application. However, the searcher obviously is not airborne nor does he possess a considerable speed advantage over the target. The pertinent question is this: Does the inapplicability of this assumption invalidate the search plan as devised by Koopman?

In order to analyze this problem, a computer simulation model was designed. Various combinations of target speed, time late and searcher speed were used to construct the Koopman search plan. By observing figure

two, it is obvious that to be effective against a target whose course is assumed to be uniformly distributed between zero and 360 degrees, a minimum of one circuit or four search legs should be completed. The computer simulation constructed four legs of the search plan for each combination of target speed, searcher speed and time late. The program gave the time required to conduct one circuit of the search plan. In addition, it gives the probability of target detection as a function of actual sonar range as opposed to the estimated sonar range and resulting sweep width used in constructing the search plan. In constructing the simulation model, an option was included to allow the test of another of the basic assumptions of the Koopman search plan, namely, that of constant target speed. The program has two versions of target speed incorporated into it. In the first version the actual target speed is set equal to the estimated target speed used in constructing the search plan. The program can be changed so that the actual target speed is a random variable. In this case, the target speed is drawn from a uniform distribution. The mean of the distribution is the estimated target speed, and the end points of the interval are estimated target speed plus and minus two knots. This allows the evaluation of the search plan, when the assumption of constant target speed is not met, and an analysis of the resulting probabilities of target detection. Table I includes a tabulation of the amount of search time necessary to complete four legs of the Koopman search plan for various combinations of target speed, search speed and times late.

As previously stated, the amount of search time available is always limited. From Table I it is apparent that the amount of time necessary to complete one circuit, herein considered the minimum against a target whose course is uniformly distributed between zero and 360 degrees, is excessively large. The search time is particularly long for the most

probable cases that would be encountered in submarine versus submarine operations.

Tables I and II allow a comparison of the probability of target detection for the case where target speed is deterministic as opposed to the case where it is a random variable.

Because of the excessive amount of time required to complete the minimum number of legs of the Koopman search plan, it was decided to construct an alternate search plan that would not be susceptible to excessively long search times.

III. ALTERNATE SEARCH PLAN

A. BASIC ASSUMPTIONS OF THE ALTERNATE SEARCH PLAN

The Koopman search plan is obviously not universally applicable to submarine versus submarine search due to the excessive search time required to complete even a minimum number of search legs. The cause of this failure is obvious. By examining the multiplicative factor m where

$$m = \frac{s_0 + st}{s_0 - st}$$

the excessive time problem can be identified.

For the range of target speeds and searcher speed combinations used in compiling Tables I and II, the factor m ranges from a high value of 13 to a low value of 1.8. In the original design of the search plan, the searcher was airborne. Searcher speed was generally in the range of 140 to 160 knots. The target, either a surfaced submarine or a surface ship, generally had a top speed of approximately 25 to 30 knots. These two facts taken together show that the multiplier m was severely limited in size. In the submarine versus submarine search problem, this is not the case. By examining the formulae for the various search legs it can be seen that the formulae reduce to a common form such that

$$L_n = m^n r_1 \pm c_n$$

$$\text{where } c_n \geq 0 .$$

Therefore, for larger values of the factor m succeeding search legs become exponentially larger. This is the cause of the excessive times necessary to complete a minimum search plan. When target and searcher

speed are relatively close together and moderately large, this effect is even more pronounced. Therefore, an alternative search plan should not be limited in this manner.

Another assumption implicit in the Koopman search plan is that numerous circuits will be completed. This fact was used explicitly in arriving at the form of the r_1 distance. The sweep spacing S was also determined based on the assumption that more than one circuit would be completed. Since the searcher in the submarine application does not enjoy the prerequisite speed advantage to complete many circuits, this assumption should not be used in constructing an alternative search plan.

Intuitively then it seems that in an alternative search plan the multiplicative factor would be relatively "small" so as to allow the completion of the minimum search plan in a reasonable amount of time. Also the r_1 distance would be determined based on the assumption that few circuits could be completed. This is due to the limited amount of search effort available. In many cases tactical considerations will probably limit this time to that necessary to complete one circuit.

B. CONSTRUCTION OF AN ALTERNATE SEARCH PLAN

In order to test an alternative search plan against the Koopman search plan, a computer simulation model was developed. To allow a fair comparison of search plans, the search effort, that is search time, had to be equal for both plans. This time was set arbitrarily at four days (96 hours) for comparison purposes. The target speed was eight knots, the search speed 12 knots, and the time late was selected at four hours. The number of search legs of the Koopman search plan that could be completed in this time was then determined. The number of search legs for the alternate search plan

was likewise determined. The probability of detection as a function of actual sonar range was then calculated for both search plans and compared. In determining the best alternate search plan, it was hypothesized that the construction would be as shown in figure 3.

The distance r_1 would have the general form such that

$$r_1 = (\text{factor}) \times (\text{time late}) \times (\text{estimated target speed})$$

where the factor value was as yet undetermined. The search leg lengths would be obtained as follows:

$$L_n = (\text{multiplier})^n \times r_1$$

where the multiplier value was as yet undetermined. In determining comparison search plans, various combinations of factor values and multiplier values were used. The factor value ranged from 0.8 to 1.5 in 0.1 increments. The multiplier values used were 2.0, 3.0, 4.5 and 6.75. In all these values generated thirty-two different alternate search plans.

The computer program output allowed a direct comparison of each alternative search plan with the Koopman plan. The measure of comparison was the probability of detection as a function of actual sonar range. Although comparison values were available for all sonar ranges from zero to 60 nautical miles, the comparison was made at a sonar range of ten nautical miles. This is the sonar range estimate used in constructing the Koopman search plan values of Tables I and II.

The probability of target detection for different combinations of factor and multiplier values are shown in figure four. In this case, the actual target speed was equal to the estimated target speed. The Koopman search plan yielded a probability of target detection of .0870 under these values of target speed, searcher speed, time late and time available to

search. An alternate search plan using a factor value of 0.9 and a multiplier value of 2.0 produced the highest probability of target detection (.1490). This is considerably better than the results using the Koopman search plan.

However, this is not a fair comparison for the Koopman search plan. Koopman used the approximation for the r_1 offset distance as follows:

$$r_1 = 0.8 \times St \times TL$$

His previous approximation had been

$$r_1 = 0.9 \times St \times TL$$

The distance had been reduced because he felt that the target would not actually be on a constant course. The comparison is not fair because in the simulation model, the targets course is a constant. A better comparison would result if the Koopman search were computed using an r_1 offset of

$$r_1 = 0.9 \times St \times TL$$

based on the fact that the target course is a constant once its initial value is determined. When this is done, the probability of target detection at a sonar range of ten nautical miles is .1140 for the Koopman search plan. Therefore, using a better comparison, the best alternate search plan is still better than the Koopman search plan.

The question arises as to whether or not this particular alternate search plan is best or even better than the Koopman search plan when target speed is a random variable as opposed to being a constant equal to the estimated target speed. The simulation was run again with the actual target speed a random variable. The Koopman search plan yielded the

following values for probability of target detection at a sonar range of ten nautical miles:

$$r_1 = 0.8 \times St \times TL \quad .0750$$

$$r_1 = 0.9 \times St \times TL \quad .0990$$

The combination of factor and multiplier values that maximized the probability of target detection at a range of ten nautical miles was the same, that is a factor value of 0.9 and a multiplier value of 2.0. They produced a probability of target detection equal to .1060.

In theory what should now be done is to run the simulation for all interesting values of search speed, target speed and time late. This would be done with a set limit on the amount of search effort available. For each combination of target and search speed, the simulation would have to be run twice--once for the case where the actual target speed equals the estimated target speed and another time for the case where the target speed was a random variable. Each run would produce a different combination of factor value and multiplier value that maximized the probability of target detection. These values might be the same for the case where the target speed is deterministic and the case where it is a random variable or they might be different. One combination of factor and multiplier values might be predominant for different target speed, search speed and time late combinations. This does not necessarily have to be the case.

However, if this is not done, what is the applicability of the alternate search plan that was found best for this particular combination of searcher and target speeds and time lates with other parameter combinations? This hypothesis was tested by using the search leg values that this plan produces in the first computer simulation mentioned. The amount

of time necessary to complete four legs of the search plan for various combinations of search speed, target speed, and time late are tabulated in Table I.

Tables I and II list the probability of target detection for various combinations of search speed, target speed and time late values, using this particular alternate search plan. In the majority of the combinations the alternate search plan produces probabilities of target detection that are greater than the Koopman search plan. This is especially significant in light of the fact that the alternate search plan requires less time to complete one circuit than the Koopman search plan in all but three cases.

Ideally, given a combination of search speed, target speed, and time late, the alternate search plan that maximizes the probability of target detection for this combination should be determined.

It is interesting to note a phenomenon exhibited by both the Koopman search plan and the alternate search plan. For some combinations of target speed, searcher speed and times late, the probability of target detection is higher when the target speed is a random variable than when the target speed is deterministic. This result occurs most often when target speed and search speed are close together and the time late is large.

It is obvious that for some combinations of target initial position and a fixed speed, the target will be undetected by the searcher. However, if the target speed becomes a random variable, the searcher may be able to detect the target. Therefore, in these cases where the search plan has a low probability of target detection, randomness in target speed may increase the probability of target detection.

IV. RECOMMENDATIONS

Since the amount of time required to conduct the minimum number of search legs using the Koopman search plan is excessive, it is recommended that an alternate search plan be used. The particular alternate to be used is dependent on the target speed, searcher speed and time late. The time available to conduct the search is also a deciding factor. The particular search plan to use can be determined by using the computer program described in appendix C. If this is not possible, the alternate search plan using a factor value of 0.9 and a multiplier value of 2.0 could be used. The resulting times to complete one circuit of the search plan and the probabilities of target detection are shown in Tables I and II for various combinations of searcher speed, target speed and time lates.

APPENDIX A

TABLE I

Constants for all Comparisons
 One Circuit (Four Legs)
 Actual Sonar Range - 10 nmi
 Estimated Sonar Range - 10 nmi
 Standard Deviation of Circular
 Normal Distribution - 2 nmi
 Actual Target Speed - Estimated
 Target Speed

Time Late (HRS)	Searcher Speed (KTS)	Target Speed (KTS)	<u>Koopman Search</u> <u>Plan</u>		<u>Alternate Search</u> <u>Plan</u>	
			Search Time (HRS)	Prob. of Detection	Search Time (HRS)	Prob. of Detection
3	8	4	160.61	.4026	40.50	.4586
3	11	4	40.19	.4153	29.45	.4940
3	14	4	19.20	.4576	23.14	.4150
6	8	4	320.21	.1576	81.00	.1960
6	11	4	79.81	.1880	58.91	.2010
6	14	4	37.99	.2063	46.29	.1383
12	8	4	639.41	.0230	162.00	.0783
12	11	4	159.04	.0213	117.82	.0633
12	14	4	75.59	.0216	92.57	.0600
3	11	8	3416.89	.1240	58.91	.1670
3	14	8	364.47	.1460	46.29	.1983
6	11	8	6832.44	.0216	117.82	.0576
6	14	8	728.27	.0236	92.57	.1006
12	11	8	13,663.53	.0000	235.64	.0096
12	14	8	1,455.87	.0000	185.14	.0273
3	14	12	64,026.36	.0773	69.43	.1190
6	14	12	128,050.69	.0000	138.86	.0656
12	14	12	256,099.63	.0000	277.71	.0123

TABLE II

Constants for all Comparisons
 One Circuit (Four Legs)
 Actual Sonar Range - 10 nmi
 Estimated Sonar Range - 10 nmi
 Standard Deviation of Circular
 Normal Distribution - 2 nmi
 Actual Target Speed - Uniform
 Random Variable

Time Late (HRS)	Searcher Speed (KTS)	Target Speed (KTS)	Koopman Search Plan		Alternate Search Plan	
			Search Time (HRS)	Prob. of Detection	Search Time (HRS)	Prob. of Detection
3	8	4	160.61	.3616	40.50	.4033
3	11	4	40.19	.4000	29.45	.4040
3	14	4	19.20	.4313	23.14	.4033
6	8	4	320.21	.1113	81.00	.1266
6	11	4	79.81	.1190	58.91	.1403
6	14	4	37.99	.1486	46.29	.1310
12	8	4	639.41	.0340	162.00	.0320
12	11	4	159.04	.0376	117.82	.0356
12	14	4	75.59	.0453	92.57	.0373
3	11	8	3416.89	.1290	58.91	.1903
3	14	8	364.47	.1373	46.29	.1786
6	11	8	6832.44	.0330	117.82	.0723
6	14	8	728.27	.0456	92.57	.0643
12	11	8	13,663.57	.0086	235.64	.0213
12	14	8	1,455.87	.0166	185.14	.0193
3	14	12	64,026.36	.0810	69.43	.1463
6	14	12	128,050.69	.0190	138.86	.1516
12	14	12	256,099.63	.0026	277.71	.0186

APPENDIX B

This appendix discusses the first of the two computer simulation models used. This simulation determines the amount of time necessary to complete one circuit (four legs) of the Koopman search plan. The output of the simulation is a graph of probability of detection as a function of actual sonar range and a listing of the sixty points plotted by the graph. The program was written in Fortran IV, level G and was run on an IBM 360 digital computer.

The basic program organization is discussed next. The basic input parameters that can be changed are as follows:

<u>ALPHANUMERIC NAME</u>	<u>PARAMETER</u>	<u>VALUES</u>	<u>UNITS</u>
NTRUN	Number of targets run against a particular search plane	>1	
RS	Sonar Range	60>RS>0	NMI
SIGMA	Standard deviation of circular normal distribution	>0	NMI
S0	Initial value of searcher speed	ST < S0 ≤ 14	KTS
STE	Initial value of target speed estimate	0 < ST < S0	KTS
TL	Initial value of time late	0 < TL ≤ 12.0	HRS
ULCT	Upper limit on target course	0 < ULCT ≤ 2π	rad
LLCT	Lower limit on target course	0 ≤ LLCT < 2π	rad

For this program the input parameters mentioned above were initialized as follows:

NTRUN = 3000
RS = 10.0
SIGMA = 2.0
SO = 8.0
STE = 4.0
TL = 4.0
ULCT = 2π
LLCT = 0.0

The program then uses these initial values to compute the parameters necessary for constructing the Koopman expending square search plan. The four search leg lengths are then computed. These distances and the r_1 distance are then used to establish the (x, y) co-ordinates for each search leg end point. Using the search speed input, the time at which each of these co-ordinates is reached is determined as is the total search time necessary for the entire search plan. The headings entitled initial values for search legs one, two, three and four will be discussed after the determination of target motion is discussed. The target course is then obtained from a uniform distribution. The end points of this interval are variable as previously mentioned. In this case the target speed was selected uniformly between values of zero and 360 degrees. The target speed is then obtained from a uniform distribution. The actual target speed can be set at the estimated target speed by using the following input cards:

ULST = STE
LLST = STE

Or the actual target speed can be a random variable drawn from a uniform distribution whose end points are the estimated target speed plus or minus two knots. This is done by substituting the following cards in the input deck:

$$ULST = STE + 2.0$$

$$LLST = STE - 2.0$$

The direction and distance of the uncertainty in target position from the origin (point of fix) is then generated from a circular normal distribution. The program then uses the randomly selected target course to determine the target's velocity components in the x and y directions. Using the random target position uncertainty selected from the circular normal distribution, the initial (x, y) coordinates of the target are then determined.

The conceptual framework associated with the next section of the program is discussed in detail in this section. For each randomly selected target track there will be some time at which the target and searcher are at a minimum range. This range is called the closest point of approach or CPA range.

It is useful to think of each search leg as being extended in space past the point where the turn to the next search leg is made. At any time on any search leg the searcher's position is a function of time and his speed. That is to say:

$$(x_s, y_s) = (a_1 + a_2 t, a_3 + a_4 t)$$

where

a_1 = search leg initial x- coordinate

a_3 = search leg initial y- coordinate

a_2 = searcher x- velocity component

a_4 = searcher y- velocity component

In a similar manner the target's position can be expressed as follows;

$$(x_t, y_t) = (b_1 + b_2 t, b_3 + b_4 t)$$

where

b_1 = target's initial x- coordinate

b_3 = target's initial y- coordinate

b_2 = target's x- velocity component

b_4 = target's y- velocity component

It also can be shown that the searcher/target range is obtained as follows:

$$\text{Range} = \sqrt{(x_s - x_t)^2 + (y_s - y_t)^2}$$

Now to minimize this range the derivative of the equation with respect to time is taken and then is set equal to zero. This procedure yields the time at which the CPA range occurs. This time is given by the following equation:

$$t_{rcpa} = \frac{(a_1 - b_1)(a_2 - b_2) + (a_3 - b_3)(a_4 - b_4)}{(a_2 - b_2)^2 + (a_4 - b_4)^2}$$

If this time actually occurs while the searcher is traversing this search leg, the range at this time is a candidate for a minimum range. If the minimum range on this search leg does not occur on the interior of the search leg interval, then it must be an end point solution. The target/searcher range, when the searcher is at the end points of each search leg, is then easily determined.

The target's speed is a constant once selected. Therefore, the x,y velocity components are constants. The target's initial position is also constant once determined. On a particular search leg the searcher x,y velocity components are constants. One is identically zero, depending

on the orientation of the search leg. Therefore, for each search leg there are at most three candidates for the CPA range and at the least two. If the solution to the time equation falls within the time frame that the searcher is on this particular search leg, then there are three candidates for a minimum on this search leg. These three are the search leg end point ranges and the range at the time equation solution. If the time value that satisfies the equation occurs when the searcher is not on this particular search leg then there are only two candidates for a minimum range, the search leg end point ranges. Using this procedure all possible candidates for minima can be obtained for the entire search plan. Once the CPA range for the iteration has been determined, it is placed in a tally box. There are sixty tally boxes. Each tally box corresponds to an interval of one nautical mile. Once the program has determined the CPA range for each target, this range is placed in the tally box for the interval into which it falls. All CPA ranges in excess of sixty nautical miles were placed in the last tally box. The program tests at this point to determine if the required number of targets have been run against this particular search plan. If not, the program generates another set of target parameters and repeats the above mentioned step. If the required number of runs has been obtained, the program sums all the tally box values and then determines the probability that the CPA range will fall in the interval of each of the individual tally boxes. This information allows the calculation of the probability that the CPA range will be less than or equal to a particular range. In essence this is the probability of target detection as a function of the actual sonar range. The output of the program is twofold. First, a print out of the probability of target detection as a function of sonar range is provided.

These values are listed for every nautical mile between one and sixty nautical miles. Secondly, the probability of target detection as a function of sonar range is plotted graphically for values of sonar range from zero to sixty nautical miles. The program then varies the searcher speed, target speed and time late to obtain all the combinations shown in Tables I and II.

The probability of target detection as a function of actual sonar range is in fact an empirical cumulative distribution function. The number of iterations performed of different target tracks (3000) ensures that the empirical cumulative distribution function will be within $\pm .025$ units of the population cumulative distribution function. This is with a probability of .95, that is to say $\alpha = .05$. The exact number of runs needed was arrived at using Kolmogorov's statistic. These values are tabulated in Table A21-b of Ref. 2.

The pseudorandom number generator used was tested for randomness using a separate computer program not described in the thesis. The statistical tests for randomness used were the frequency test, serial test, lagged product test, runs up and down test, and runs above and below the mean test. The pseudorandom number test passes all of these tests adequately, thereby justifying its use.

It should be noted that by replacing the r_1 distance calculation and the search leg length computations for the Koopman plan by those necessary for the alternate search plan, the same output can be obtained for the alternate search plan. The following card must be removed:

$$SM = (SO + STE)/(SO - STE)$$

$$r_1 = 0.8 * STE * TL$$

$$SL1 = SM * r_1$$

$SL2 = SM * SL1 + r_1$

$SL3 = SM * SL2$

$SL4 = SM * SL3 + A$

Once these cards have been removed the following cards have to be inserted in their places:

$SM = 2.0$

$r_1 = 0.9 * STE * TL$

$SL1 = SM * r_1$

$SL2 = SM ** 2 * r_1$

$SL3 = SM ** 3 * r_1$

$SL4 = SM ** 4 * r_1$

The program will then determine the values depicted by Tables I and II for the alternate search plan that was determined to be best.

APPENDIX C

This appendix describes the second computer simulation used in the analysis and comparison of search plans. The primary purpose of this simulation is to compare alternate search plans with the Koopman search plan. Therefore, the goal of this simulation is to compare search plans which require the same amount of search effort, that is search time.

With this goal in mind, the input variables were chosen as follows:

<u>ALPHANUMERIC NAME</u>	<u>PARAMETER</u>	<u>VALUES</u>	<u>UNITS</u>
STE	Estimated target speed	$0 < STE < S_0$	KTS
S ₀	Searcher speed	$STE < S_0$	KTS
TL	Time late	>0	HRS
TLimit	Amount of search time available	>0	HRS
NTRUNS	Number of target runs against a particular search plan	>0	
ULCT	Upper limit target course	$0 < ULCT \leq 2\pi$	RADIANS
LLCT	Lower limit target course	$0 \leq LLCT < 2\pi$	RADIANS
SIGMA	Standard deviation of circular normal distribution	>0	NMI
RS	Sonar Range	>0	NMI

The program was run with the following initial values for these parameters:

STE = 8.0
S₀ = 12.0
TL = 4
NTRUNS = 3000
ULCT = 2π
LLCT = 0.0

SIGMA = 2.0

RS = 10.0

The program input considered next is the actual target speed input. There are two options available. First the following two cards may be used:

ULST = STE

LLST = STE

When used, these cards result in the actual target speed being a constant equal to the estimated target speed. The second option involves inserting the following cards into the deck:

ULST = STE + 2.0

LLST = STE - 2.0

This results in the actual target speed for each iteration being drawn from a uniform distribution. The mean of the distribution is the estimated target speed while the end points are the estimated target speed plus and minus two knots. The program then computes the parameters necessary for the calculation of the Koopman search plan. The (x,y) coordinate values for each of these search leg end points is then calculated. This having been done, the values for twenty search legs were computed. The values necessary to determine the searcher's initial position and velocity component for each of the search legs is computed. The program then determines the time that the searcher will reach each of the search leg end points. The procedure stops the first instance in which this time exceeds the limit of the search time available. By so doing, the number of search legs or parts of search legs that can be completed in the search time available has been determined. The target's course is then selected from a uniform distribution. The limits of this distribution are variable and have been

previously mentioned. The target's position uncertainty is then selected from a circular normal distribution. The next target parameter determined is target speed. This speed comes from a uniform distribution as mentioned before.

The target's initial (x,y) coordinates are then determined. The target's velocity components in the x,y direction are calculated next. The candidates for the minimum target/searcher range are then calculated using the procedure fully explained in appendix A. From these a CPA range for this target iteration is determined. This range is placed in a tally box and the procedure is repeated until the required number of target iterations has been performed. When this has occurred, the probability of target detection as a function of sonar range is calculated.

The input parameters for the alternate search plan are now listed. They are as follows:

OMULT = 2.0

FACTOR = 0.8

The factor value is used in determining the r_1 distance as follows:

$$r_1 = \text{FACTOR} * \text{STE} * \text{TL}$$

and the quantity OMULT is used in determining the search leg lengths where

$$L_n = \text{OMULT}^n(r_1)$$

The value of twenty-four search leg's lengths for each FACTOR and OMULT combination are then determined. The (x,y) coordinates values for each search leg are calculated. The parameters necessary for the target/searcher minimum range calculation are determined at this point. The number of full and partial search legs that the target can complete in the allotted search time is then determined. The target course, speed

and position uncertainty values are then determined. The closest point of approach is determined for this iteration. This CPA range is placed in a tally box. The program tests to see if the desired number of targets have been run for this search plan. If they have not, it generates targets until the required number has been reached. For each target it computes the CPA range and places it in a tally box. The program then computes the values of probability of target detection as a function of sonar range.

These values are then printed for the Koopman search plan and the particular alternate search plan under consideration. The program then plots the graph of probability of detection as a function of sonar range. The values for the Koopman search plan and the particular alternate search plan under consideration are then plotted on the same graph. This is done to facilitate comparison. The factor value used in the r_1 determination and then the multiplier value used in the search leg length calculation are then varied. The entire alternate search is then recalculated. The required number of targets are run against this search plan and the probability of detection as a function of sonar range is calculated. Once these values are calculated they are printed out and plotted for easy comparison with the Koopman search plan.

APPENDIX D

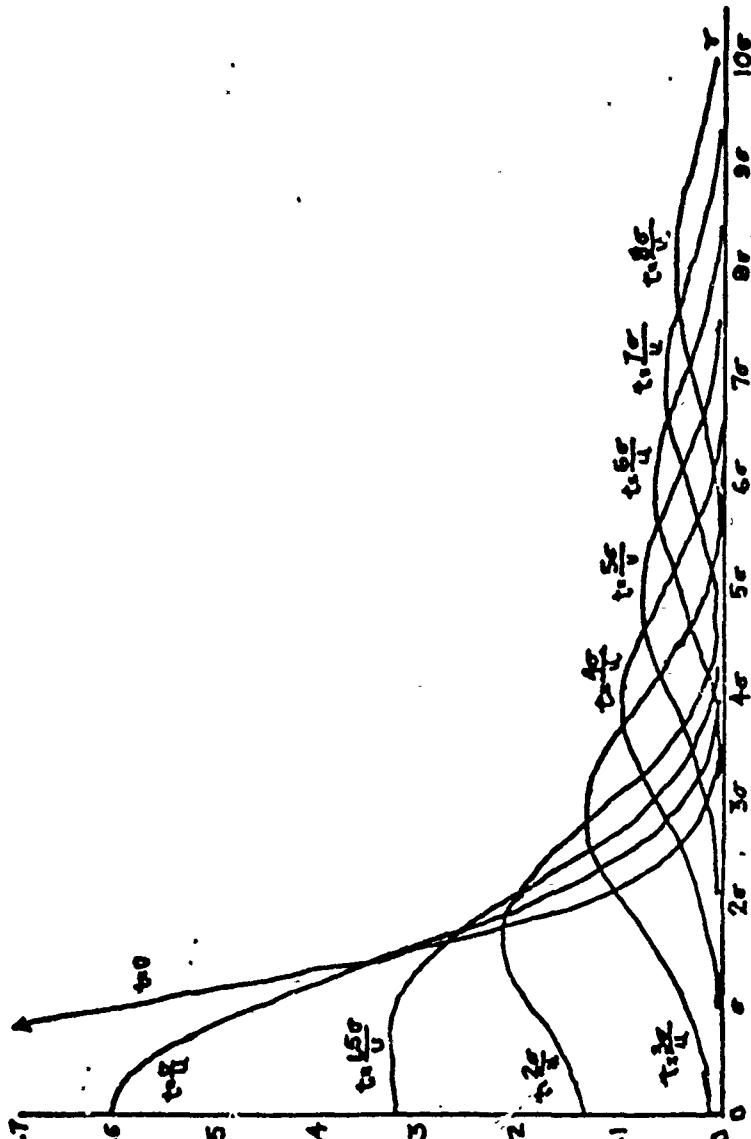


figure 1

Distance r from point of fix
Distribution of a moving target about
a point of fix o

KOOPMAN SEARCH PLAN

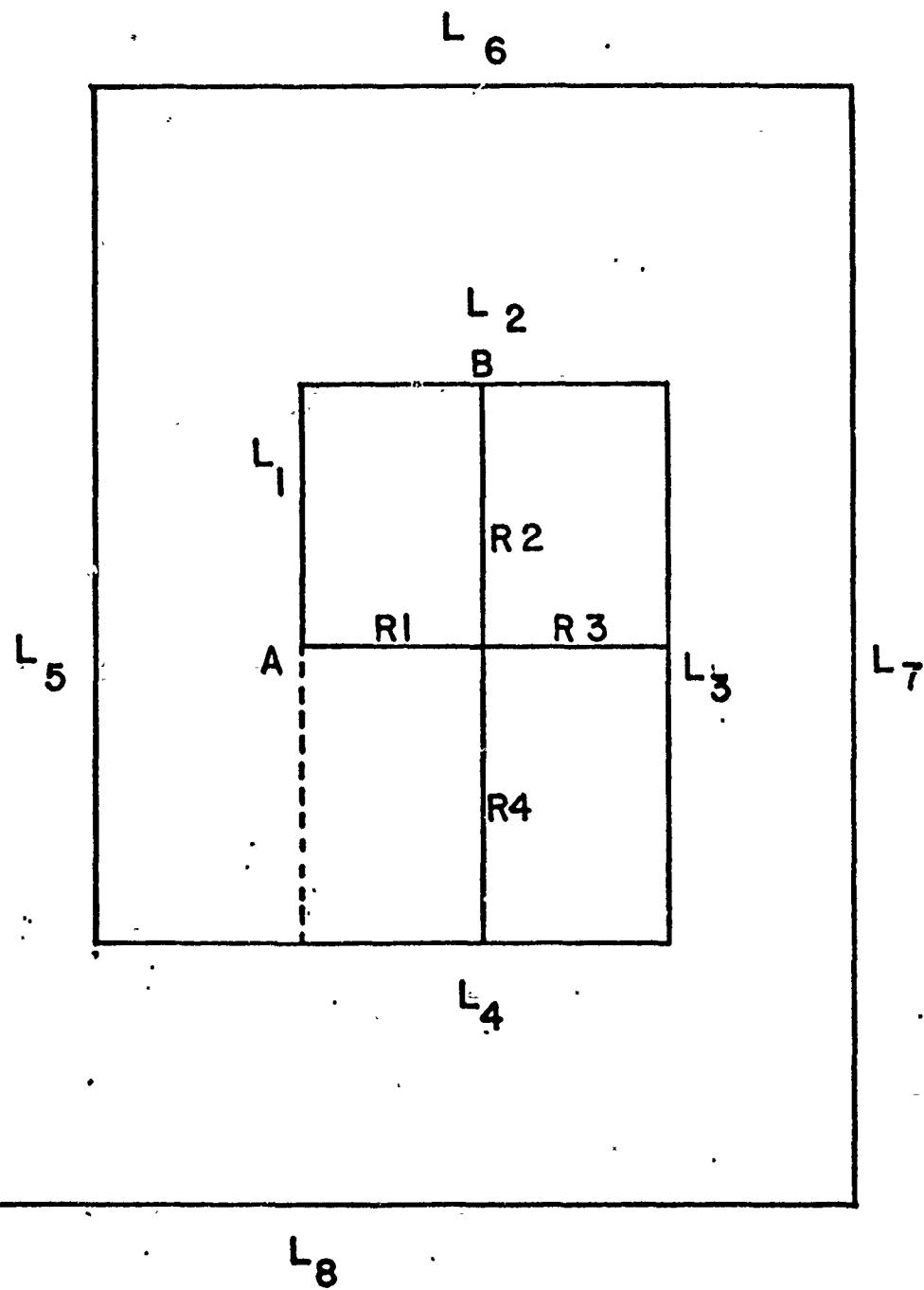
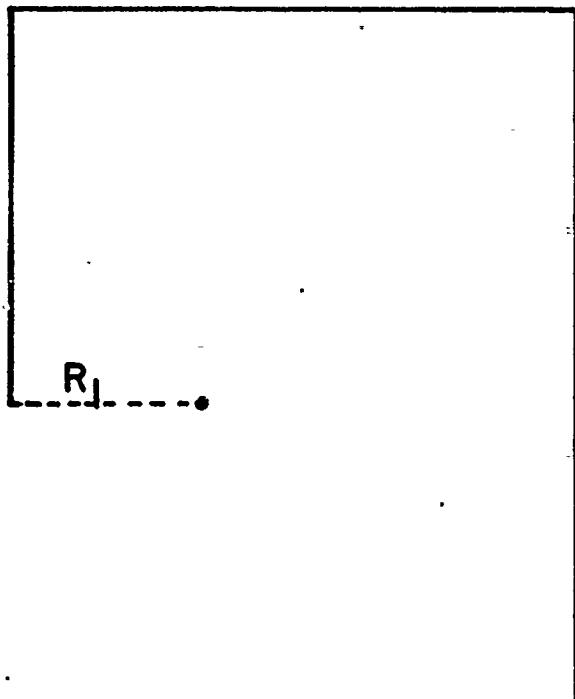


figure 2

ALTERNATE SEARCH PLAN

$$L_2 = M^2 R_1$$

$$L_1 = M R_1$$



R₁

$$-3 = M^3 R_1$$

$$L_4 = M^4 R_1$$

figure 3

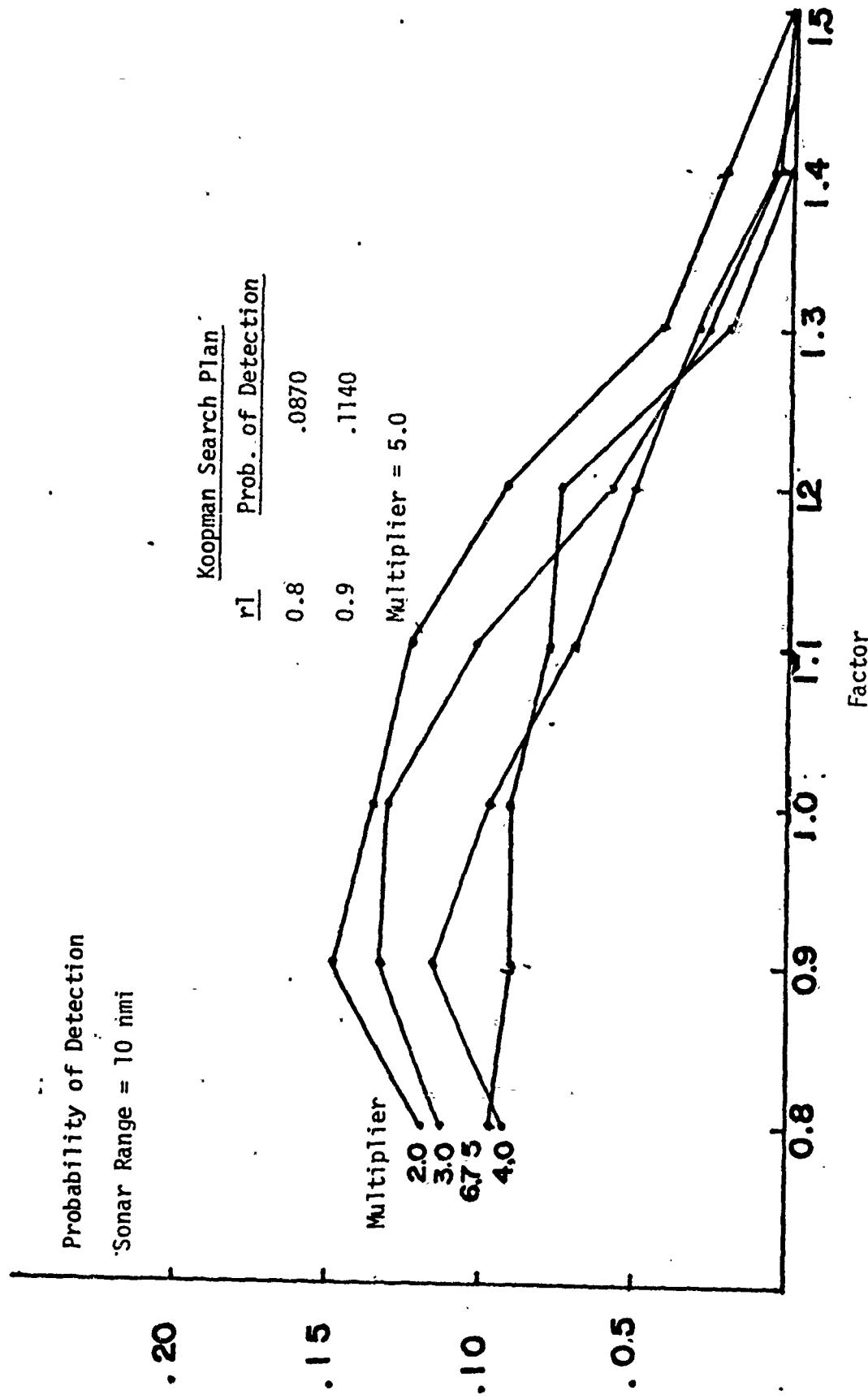


figure 4

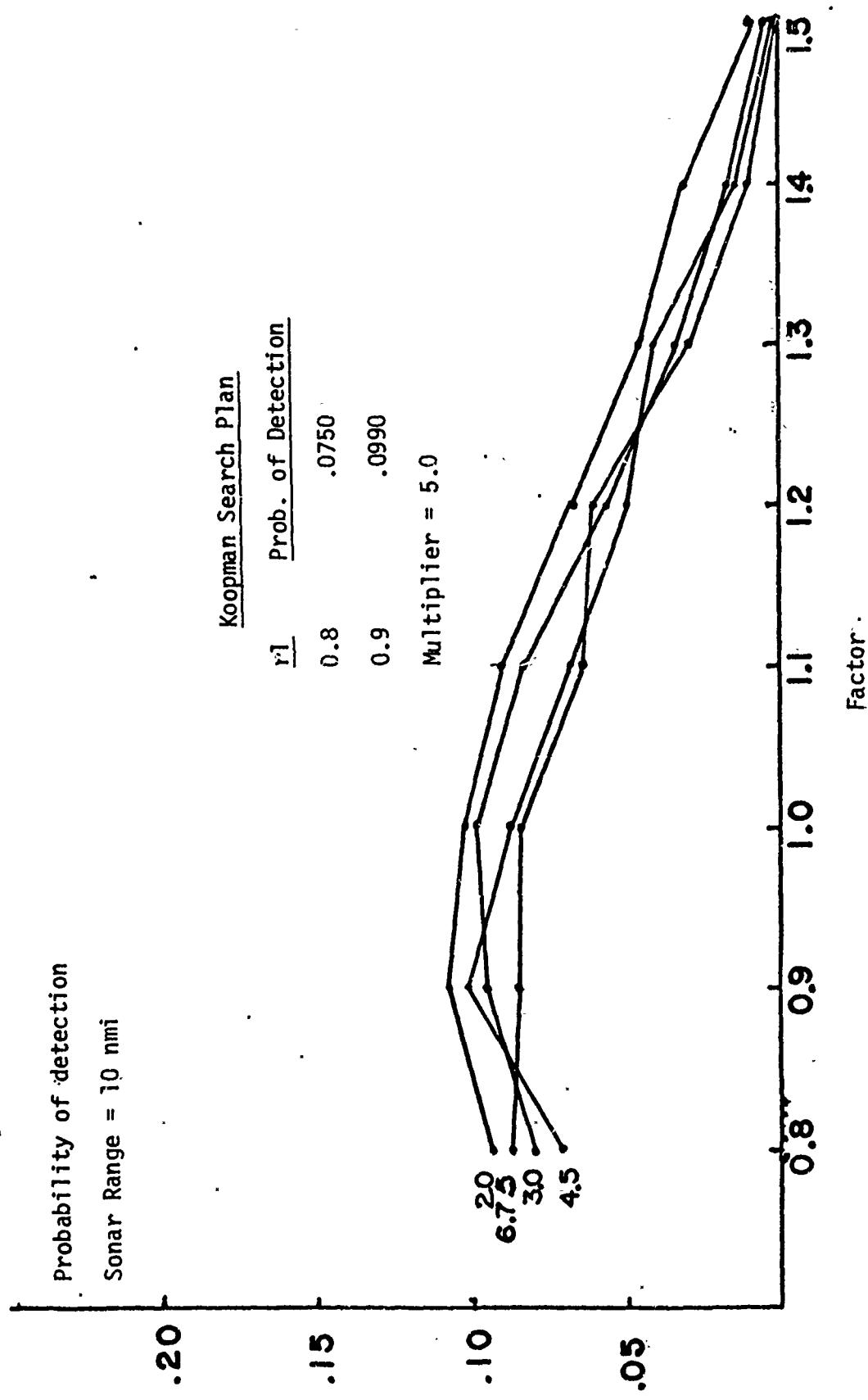


figure 5

COMPUTER OUTPUT

A sample of the computer output is included in this section for each of the programs used. The output for the first program consists of a listing of the probabilities of target detection for actual sonar ranges for a limited number of target speeds, searcher speeds and times late combinations. After each listing, the same information is presented in a graphical format. The x-axis represents actual sonar range in nautical miles, and the y-axis is the probability of target detection. In using the listing, a computer design feature made the following convention necessary:

Probability of Target Detection = CDF(x+1)
for Sonar Range of x nmi

The output of the second computer program consists of comparative listings and comparative graphs for the input parameters specified in the program explanation of Appendix C. The listings and graphical results are given for the Koopman search plan and the alternate search plans. The alternate search plans used a multiplier value of 2.0 and factor values of 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, and 1.5. The same convention is used for the listings. The axes of the graphs are also the same. In the graphical representation of the results, the Koopman search plan values are denoted by "." and the alternate search plan values are denoted by "+". In the case where the values of the Koopman search plan and the alternate search plan under consideration are the same, only the value for the alternate search plan (+) is printed. The exact probability of target detection at a particular sonar range can be obtained from the listings.

KCCPMAN SEARCH PLAN
SEARCHER SPEED = 8.0
ASSUMED TARGET SPEED = 4.0
TIME LATE = 3.0
TOTAL SEARCH TIME = 163.61

CCF 1=C.0
CCF 2=C.0C300
CCF 3=C.01567
CCF 4=C.04967
CCF 5=C.10033
CCF 6=C.15333
CCF 7=C.2C800
CCF 8=C.25667
CCF 9=C.3C933
CCF 10=C.36267
CCF 11=C.4C267
CCF 12=C.42933
CCF 13=C.45333
CCF 14=C.48200
CCF 15=C.51033
CCF 16=C.53967
CCF 17=C.57267
CCF 18=C.6C700
CCF 19=C.66567
CCF 20=C.72700
CCF 21=C.80833
CCF 22=C.88433
CCF 23=C.95633
CCF 24=C.98567
CCF 25=C.99433
CCF 26=C.99933
CCF 27=1.C0000
CCF 28=1.C00000
CCF 29=1.CC000
CCF 30=1.C00000
CCF 31=1.CC0000
CCF 32=1.CC0000
CCF 33=1.C00000
CCF 34=1.C00000
CCF 35=1.CCOC0
CCF 36=1.C00000
CCF 37=1.C00000
CCF 38=1.CCC000
CCF 39=1.CC0000
CCF 40=1.C00000
CCF 41=1.CC0000
CCF 42=1.CC0000
CCF 43=1.C00000
CCF 44=1.CC0000
CCF 45=1.CC0000
CCF 46=1.C00000
CCF 47=1.CCC000
CCF 48=1.CC0000
CCF 49=1.C00000
CCF 50=1.CCCCC0
CCF 51=1.C00000
CCF 52=1.C00000
CCF 53=1.C00000
CCF 54=1.C00000
CCF 55=1.C00000
CCF 56=1.CC0000
CCF 57=1.CC0000
CCF 58=1.C00000
CCF 59=1.CC0000
CCF 60=1.C00000
CCF 61=1.C00000

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KCCPMAN SEARCH PLAN
SEARCHER SPEED=14.0
ASSUMED TARGET SPEED= 4.0
TIME LATE= 3.0
TCTAL SEARCH TIME = 22.20

CCF 1=C.0
CCF 2=0.00533
CCF 3=0.02200
CCF 4=0.06600
CCF 5=0.12833
CCF 6=0.19333
CCF 7=0.25467
CCF 8=0.32100
CCF 9=0.37333
CCF 10=0.41833
CCF 11=0.45767
CCF 12=0.49667
CCF 13=0.53833
CCF 14=0.58333
CCF 15=0.62500
CCF 16=0.68400
CCF 17=0.74400
CCF 18=0.79967
CCF 19=0.85167
CCF 20=0.88167
CCF 21=0.91067
CCF 22=0.94467
CCF 23=0.97967
CCF 24=0.99133
CCF 25=0.99733
CCF 26=0.99867
CCF 27=1.00000
CCF 28=1.00000
CCF 29=1.00000
CCF 30=1.00000
CCF 31=1.00000
CCF 32=1.00000
CCF 33=1.00000
CCF 34=1.00000
CCF 35=1.00000
CCF 36=1.00000
CCF 37=1.00000
CCF 38=1.00000
CCF 39=1.00000
CCF 40=1.00000
CCF 41=1.00000
CCF 42=1.00000
CCF 43=1.00000
CCF 44=1.00000
CCF 45=1.00000
CCF 46=1.00000
CCF 47=1.00000
CCF 48=1.00000
CCF 49=1.00000
CCF 50=1.00000
CCF 51=1.00000
CCF 52=1.00000
CCF 53=1.00000
CCF 54=1.00000
CCF 55=1.00000
CCF 56=1.00000
CCF 57=1.00000
CCF 58=1.00000
CCF 59=1.00000
CCF 60=1.00000
CCF 61=1.00000

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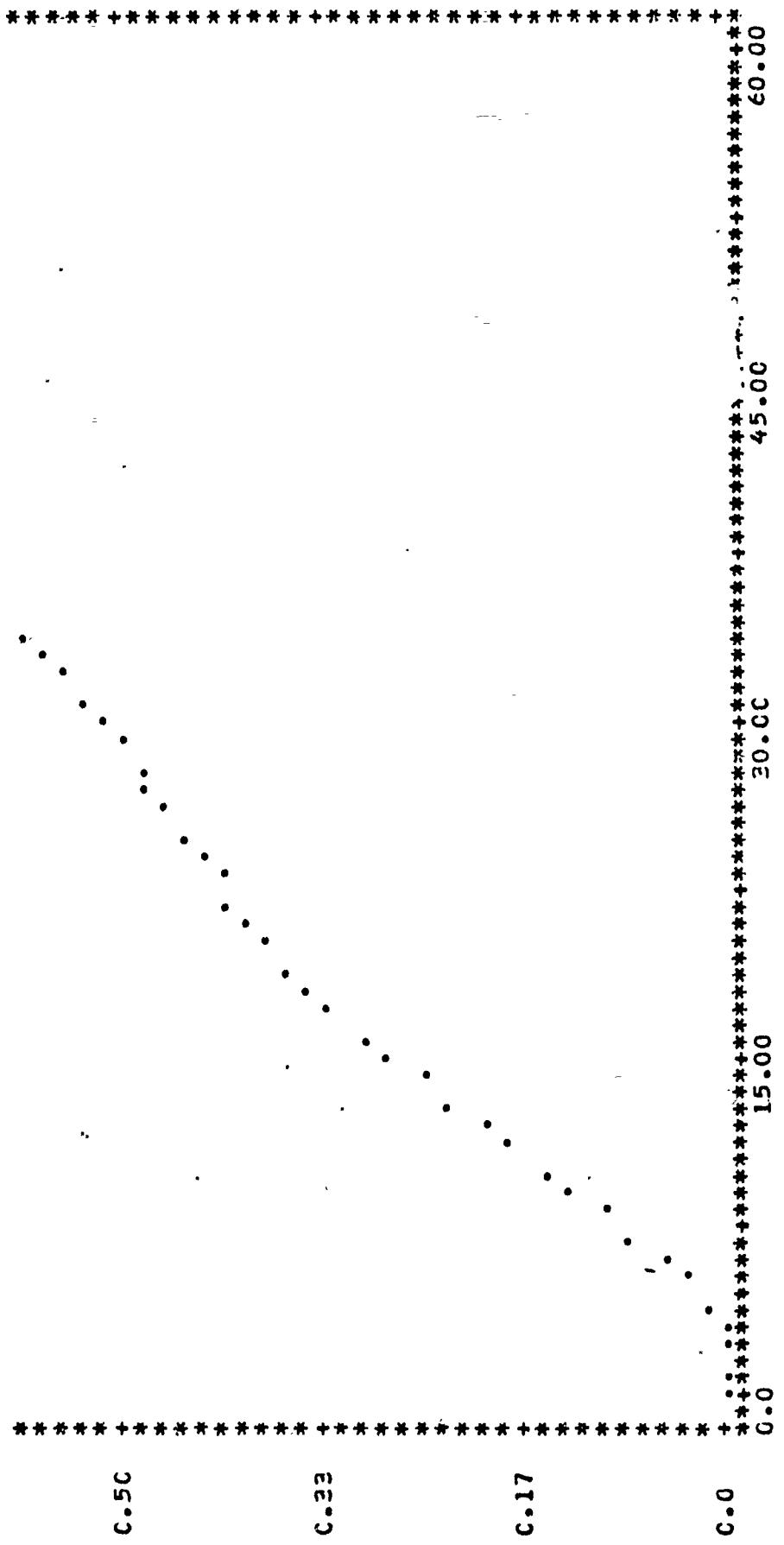
17

X-SCALE: nnn = 0.75CE 00 UNITS

SEARCH PLAN WAS CALCULATED USING THE FOLLOWING PARAMETERS
 SEARCHER SPEED = 14.0
 ASSISTANT SPEED = 4.0 C
 TARGET SPEED = 3.0
 TIME LATE = 3.0

KCCPMAN SEARCH PLAN
SEARCHER SPEED = 8.0
ASSUMED TARGET SPEED = 4.0
TIME LATE = 6.0
TOTAL SEARCH TIME = 326.21

CCF 1=0.0
CCF 2=0.0
CCF 3=0.0
CCF 4=0.00233
CCF 5=0.00900
CCF 6=0.02700
CCF 7=0.04933
CCF 8=0.07533
CCF 9=0.10067
CCF 10=0.13300
CCF 11=0.15767
CCF 12=0.18067
CCF 13=0.20567
CCF 14=0.23100
CCF 15=0.25700
CCF 16=0.28000
CCF 17=0.30333
CCF 18=0.32733
CCF 19=0.34800
CCF 20=0.36800
CCF 21=0.38500
CCF 22=0.39833
CCF 23=0.41233
CCF 24=0.42267
CCF 25=0.43733
CCF 26=0.45167
CCF 27=0.46667
CCF 28=0.47867
CCF 29=0.49100
CCF 30=0.50667
CCF 31=0.51700
CCF 32=0.53400
CCF 33=0.55233
CCF 34=0.56967
CCF 35=0.59067
CCF 36=0.62033
CCF 37=0.65400
CCF 38=0.68467
CCF 39=0.71500
CCF 40=0.75533
CCF 41=0.79800
CCF 42=0.84067
CCF 43=0.89067
CCF 44=0.94533
CCF 45=0.97633
CCF 46=0.99000
CCF 47=0.99600
CCF 48=0.99933
CCF 49=0.99967
CCF 50=0.99967
CCF 51=1.00000
CCF 52=1.00000
CCF 53=1.00000
CCF 54=1.00000
CCF 55=1.00000
CCF 56=1.00000
CCF 57=1.00000
CCF 58=1.00000
CCF 59=1.00000
CCF 60=1.00000
CCF 61=1.00000



X-SCALE: 0.75×10^{-2} UNITS
 Y-SCALE: 0.167×10^{-1} UNITS

SEARCH PLAN WAS CALCULATED USING THE FOLLOWING PARAMETERS
 SEARCHER SPEED = $8^{\circ}/\text{sec}$
 ASSUMED TARGET SPEED = 4.0
 TIME LATE = 6.0

KCCPMAN SEARCH PLAN
SEARCHER SPEED=14.0
ASSUMED TARGET SPEED= 4.0
TIME LATE= 6.0
TOTAL SEARCH TIME = 43.99

CDF 1=C.0
CDF 2=C.0
CDF 3=0.00100
CDF 4=0.00433
CDF 5=0.01233
CDF 6=C.03100
CDF 7=0.06833
CDF 8=C.10900
CDF 9=C.14367
CDF 10=C.17867
CDF 11=C.20633
CDF 12=C.22967
CDF 13=C.25867
CDF 14=C.29467
CDF 15=0.32633
CDF 16=C.36100
CDF 17=C.38667
CDF 18=C.41100
CDF 19=C.43367
CDF 20=C.45500
CDF 21=C.47333
CDF 22=C.49767
CDF 23=C.52000
CDF 24=0.53933
CDF 25=C.55800
CDF 26=C.58033
CDF 27=C.59833
CDF 28=C.62133
CDF 29=C.64867
CDF 30=C.66833
CDF 31=C.69367
CDF 32=C.72467
CDF 33=C.75367
CDF 34=C.78467
CDF 35=C.81500
CDF 36=C.84033
CDF 37=C.86067
CDF 38=C.87167
CDF 39=C.87867
CDF 40=C.88700
CDF 41=C.90267
CDF 42=C.92633
CDF 43=0.95100
CDF 44=C.97800
CDF 45=C.99200
CDF 46=C.99633
CDF 47=0.99900
CDF 48=C.99933
CDF 49=0.99967
CDF 50=1.00000
CDF 51=1.00000
CDF 52=1.00000
CDF 53=1.00000
CDF 54=1.00000
CDF 55=1.00000
CDF 56=1.00000
CDF 57=1.00000
CDF 58=1.00000
CDF 59=1.00000
CDF 60=1.00000
CDF 61=1.00000

C.50

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0.0 0.0 30.00 45.00 60.00

X-SCALE := 0.75CE 00 UNITS
Y-SCALE := 0.167E-01 UNITS

SEARCH PLAN WAS CALCULATED USING THE FOLLOWING PARAMETERS

SEARCHER SPEED = 14.0
ASSISTANT TARGET SPEED = 4.0
TIME LATE = 6.0

KCCPMAN SEARCH PLAN
SEARCHER SPEED= 8.0
ASSUMED TARGET SPEED= 4.0
TIME LATE=12.0
TOTAL SEARCH TIME = 651.41

CCF 1=0.0
CCF 2=0.0
CCF 3=0.0
CCF 4=0.0
CCF 5=0.0
CCF 6=0.0
CCF 7=0.0
CCF 8=0.00133
CCF 9=0.00333
CCF 10=0.00867
CCF 11=0.02300
CCF 12=0.03533
CCF 13=0.04600
CCF 14=0.06100
CCF 15=0.07700
CCF 16=0.08833
CCF 17=0.10267
CCF 18=0.12133
CCF 19=0.13633
CCF 20=0.15233
CCF 21=0.16700
CCF 22=0.17567
CCF 23=0.18567
CCF 24=0.19900
CCF 25=0.21100
CCF 26=0.22533
CCF 27=0.23567
CCF 28=0.24567
CCF 29=0.25633
CCF 30=0.26700
CCF 31=0.28033
CCF 32=0.29400
CCF 33=0.30467
CCF 34=0.31733
CCF 35=0.33033
CCF 36=0.34000
CCF 37=0.35033
CCF 38=0.36267
CCF 39=0.37767
CCF 40=0.38833
CCF 41=0.39767
CCF 42=0.40433
CCF 43=0.41100
CCF 44=0.41633
CCF 45=0.42233
CCF 46=0.42833
CCF 47=0.43467
CCF 48=0.43867
CCF 49=0.44400
CCF 50=0.45000
CCF 51=0.45733
CCF 52=0.46433
CCF 53=0.47000
CCF 54=0.47667
CCF 55=0.48533
CCF 56=0.48900
CCF 57=0.49400
CCF 58=0.50000
CCF 59=0.50733
CCF 60=0.51367
CCF 61=1.00000

C.5C

C.33

C.17

C.0

X-SCALE: 0.00 = 0.75CE CO UNITS
Y-SCALE: 0.00 = 0.167E-01 UNITS

X-SCALE: 15.00 = 30.0C CO UNITS
Y-SCALE: 4.50 = 4.5.CC CO UNITS

X-SCALE: 30.00 = 60.0C CO UNITS
Y-SCALE: 4.50 = 60.0CC CO UNITS

SEARCH PLAN WAS CALCULATED USING THE FOLLOWING PARAMETERS
SEARCHER SPEED= 8.0
ASPECT TARGET SPEED= 4.0
TIME LATE=12.0

KCCPMAN SEARCH PLAN
SEARCHER SPEED=14.0
ASSUMED TARGET SPEED= 4.0
TIME LATE=12.0
TOTAL SEARCH TIME = 87.58

CCF 1=C.0
CCF 2=C.0
CCF 3=C.0
CCF 4=C.0
CCF 5=C.0
CCF 6=C.0
CCF 7=C.0
CCF 8=C.0
CCF 9=C.00333
CCF 10=C.CC767
CCF 11=C.02167
CCF 12=0.C4200
CCF 13=C.06533
CCF 14=C.C8833
CCF 15=C.1C900
CCF 16=C.12700
CCF 17=0.14300
CCF 18=C.15767
CCF 19=C.17267
CCF 20=C.18633
CCF 21=C.20000
CCF 22=C.21400
CCF 23=C.22600
CCF 24=C.24000
CCF 25=C.25400
CCF 26=C.26833
CCF 27=C.28200
CCF 28=C.29400
CCF 29=C.31267
CCF 30=C.33367
CCF 31=C.35067
CCF 32=C.36467
CCF 33=C.37767
CCF 34=C.38933
CCF 35=C.40300
CCF 36=C.41533
CCF 37=C.42400
CCF 38=C.43267
CCF 39=C.44133
CCF 40=C.44867
CCF 41=0.46033
CCF 42=C.47C33
CCF 43=C.48133
CCF 44=C.49267
CCF 45=C.5C267
CCF 46=C.51033
CCF 47=C.52033
CCF 48=C.53300
CCF 49=C.54267
CCF 50=C.55033
CCF 51=C.56033
CCF 52=C.57133
CCF 53=C.58333
CCF 54=C.59500
CCF 55=C.60600
CCF 56=C.62133
CCF 57=C.63567
CCF 58=0.64500
CCF 59=C.66100
CCF 60=C.67867
CCF 61=1.00000

X-SCALE: "*= 0.75CE CO UNITS
Y-SCALE: "*= 0.167E-01 UNITS

SEARCHER SPEED=14.0
ASSISTANT TARGET SPEED= 4.0
TIME LATE=12.0

SEARCH PLAN WAS CALCULATED USING THE FOLLOWING PARAMETERS

SEARCHER SPEED=12.0
 ASSUMED TARGET SPEED= 8.0
 TIME LATE= 4.0
 TOTAL SEARCH TIME= 96.00

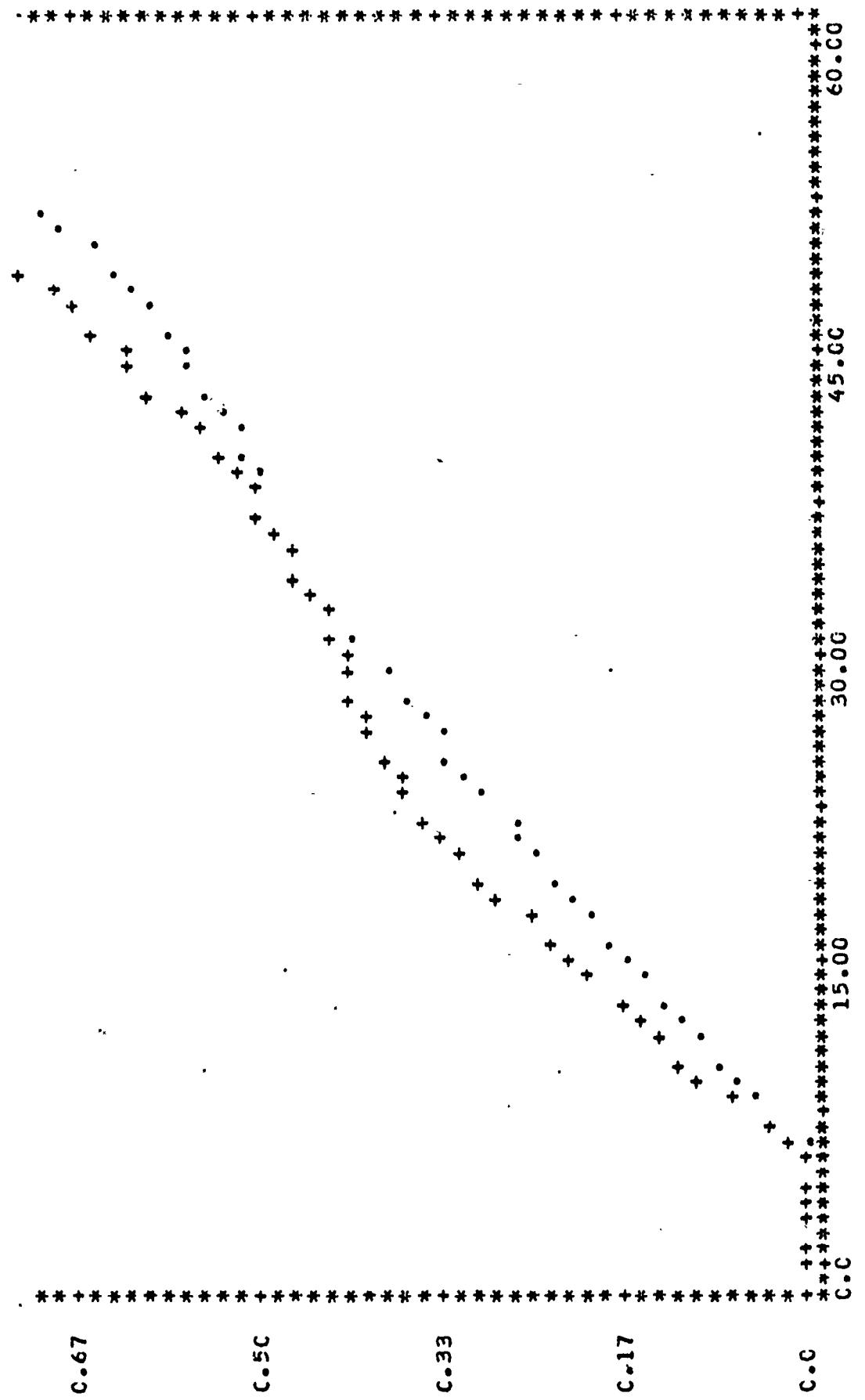
KCCPMAN
SEARCH
PLAN

ALTERNATE
SEARCH
PLAN

FACTOR= 0.8 MULTIPLIER= 2.00

CDF 1=C.0
CDF 2=C.0
CDF 3=C.0
CDF 4=C.C
CDF 5=C.0010
CDF 6=C.0C3C
CDF 7=C.006C
CDF 8=C.025C
CDF 9=C.045C
CDF 10=C.067C
CDF 11=C.087C
CDF 12=C.105C
CDF 13=C.1200
CDF 14=C.138C
CDF 15=C.155C
CDF 16=C.169C
CDF 17=C.188C
CDF 18=C.202C
CDF 19=C.214C
CDF 20=C.229C
CDF 21=C.244C
CDF 22=C.259C
CDF 23=C.274C
CDF 24=C.292C
CDF 25=C.312C
CDF 26=C.327C
CDF 27=C.341C
CDF 28=C.356C
CDF 29=C.372C
CDF 30=C.391C
CDF 31=C.409C
CDF 32=C.424C
CDF 33=C.439C
CDF 34=C.448C
CDF 35=C.460C
CDF 36=C.473C
CDF 37=C.480C
CDF 38=C.492C
CDF 39=C.501C
CDF 40=C.506C
CDF 41=C.517C
CDF 42=C.522C
CDF 43=C.524C
CDF 44=C.548C
CDF 45=C.566C
CDF 46=C.568C
CDF 47=C.579C
CDF 48=C.593C
CDF 49=C.611C
CDF 50=C.630C
CDF 51=C.652C
CDF 52=C.676C
CDF 53=C.704C
CDF 54=C.727C
CDF 55=C.760C
CDF 56=C.794C
CDF 57=C.849C
CDF 58=C.910C
CDF 59=C.963C
CDF 60=C.992C
CDF 61=1.000C

CDF 1=0.0
CDF 2=0.0
CDF 3=0.0
CDF 4=0.0
CDF 5=0.0
CDF 6=0.0040
CDF 7=0.0130
CDF 8=0.0370
CDF 9=C.0600
CDF 10=C.0920
CDF 11=C.1170
CDF 12=C.1320
CDF 13=C.1450
CDF 14=C.1680
CDF 15=C.1920
CDF 16=C.213C
CDF 17=C.2360
CDF 18=C.255C
CDF 19=C.2770
CDF 20=C.298C
CDF 21=C.3100
CDF 22=C.3330
CDF 23=C.350C
CDF 24=C.363C
CDF 25=C.3710
CDF 26=C.386C
CDF 27=C.3920
CDF 28=C.398C
CDF 29=C.409C
CDF 30=C.419C
CDF 31=C.423C
CDF 32=C.431C
CDF 33=C.439C
CDF 34=C.450C
CDF 35=C.454C
CDF 36=C.471C
CDF 37=C.485C
CDF 38=C.494C
CDF 39=C.508C
CDF 40=C.522C
CDF 41=C.541C
CDF 42=C.553C
CDF 43=C.571C
CDF 44=C.596C
CDF 45=C.611C
CDF 46=C.624C
CDF 47=C.644C
CDF 48=C.666C
CDF 49=C.6900
CDF 50=C.715C
CDF 51=C.741C
CDF 52=C.7700
CDF 53=C.791C
CDF 54=C.825C
CDF 55=C.843C
CDF 56=C.865C
CDF 57=C.887C
CDF 58=C.921C
CDF 59=C.967C
CDF 60=C.986C
CDF 61=1.000C



X-SCALE: 10^0 Y-SCALE: 10^0 UNITS

SEARCHER SPEED=12.0
 ASSUMED TARGET SPEED= 8.0
 TIME LATE= 4.0
 TOTAL SEARCH TIME= 96.00

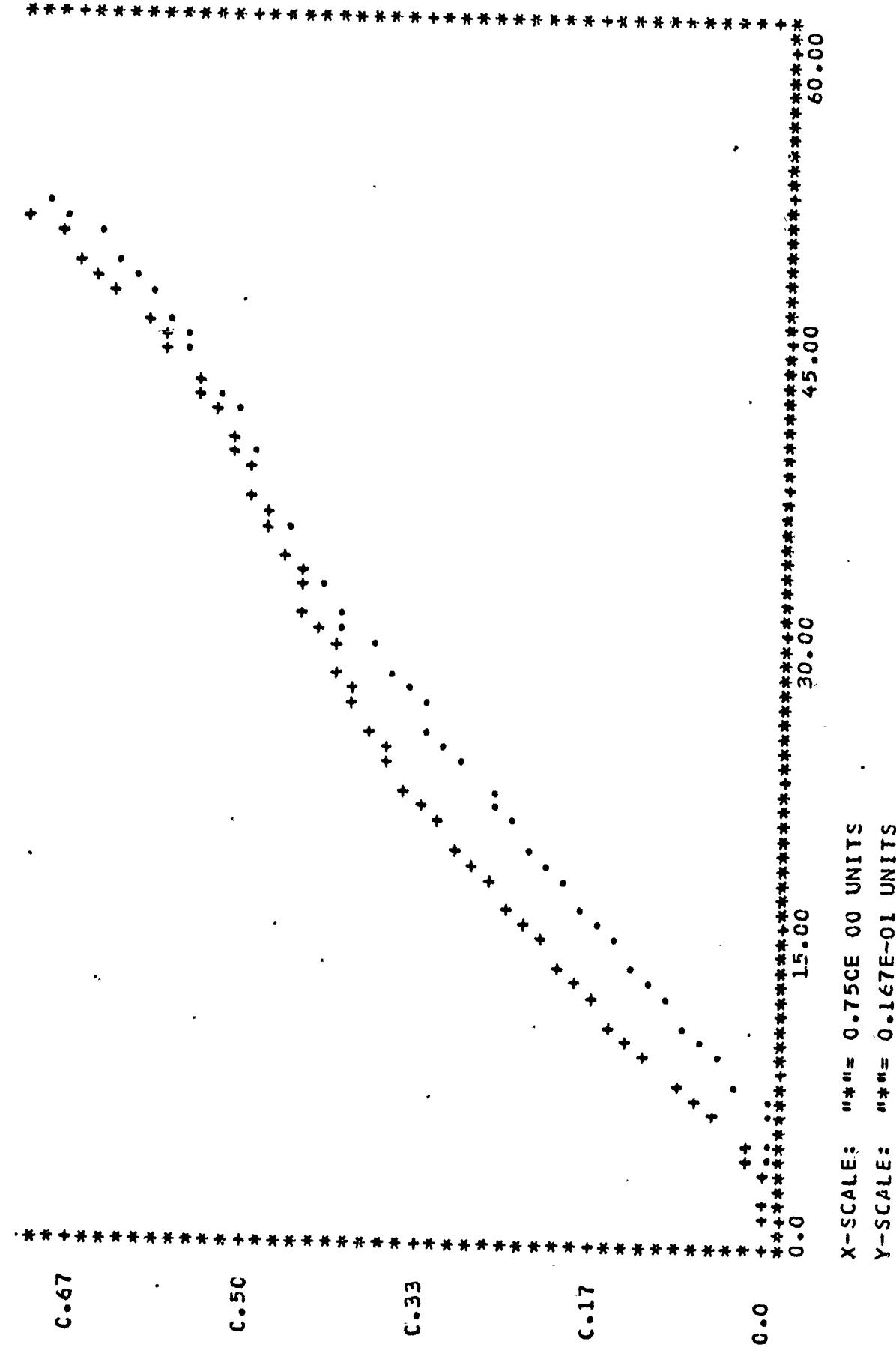
KCCPMAN
SEARCH
PLAN

ALTERNATE
SEARCH
PLAN

FACTOR= 0.9 MULTIPLIER= 2.00

CDF 1=C.0
CDF 2=C.0
CDF 3=C.0
CDF 4=C.0
CDF 5=C.001C
CDF 6=C.003C
CDF 7=C.006C
CDF 8=C.025C
CDF 9=C.045C
CDF 10=C.067C
CDF 11=C.087C
CDF 12=C.1C5C
CDF 13=C.12C0
CDF 14=C.138C
CDF 15=C.155C
CDF 16=C.169C
CDF 17=C.188C
CDF 18=C.202C
CDF 19=C.214C
CDF 20=C.229C
CDF 21=C.244C
CDF 22=C.259C
CDF 23=C.274C
CDF 24=C.292C
CDF 25=C.312C
CDF 26=C.327C
CDF 27=C.341C
CDF 28=C.356C
CDF 29=C.372C
CDF 30=C.391C
CDF 31=C.409C
CDF 32=C.424C
CDF 33=C.439C
CDF 34=C.448C
CDF 35=C.460C
CDF 36=C.473C
CDF 37=C.480C
CDF 38=C.492C
CDF 39=C.5C1C
CDF 40=C.506C
CDF 41=C.517C
CDF 42=C.522C
CDF 43=C.534C
CDF 44=C.548C
CDF 45=C.566C
CDF 46=C.568C
CDF 47=C.579C
CDF 48=C.593C
CDF 49=C.611C
CDF 50=C.630C
CDF 51=C.652C
CDF 52=C.676C
CDF 53=C.704C
CDF 54=C.727C
CDF 55=C.760C
CDF 56=C.794C
CDF 57=C.849C
CDF 58=C.910C
CDF 59=C.963C
CDF 60=C.992C
CDF 61=1.000C

CDF 1=0.0
CDF 2=0.0030
CDF 3=0.0050
CDF 4=0.0090
CDF 5=0.0240
CDF 6=0.0460
CDF 7=0.0600
CDF 8=0.0890
CDF 9=0.1110
CDF 10=0.1330
CDF 11=0.1490
CDF 12=0.1650
CDF 13=0.1860
CDF 14=0.2020
CDF 15=0.2200
CDF 16=0.2350
CDF 17=0.2510
CDF 18=0.2700
CDF 19=0.2800
CDF 20=0.2960
CDF 21=0.3190
CDF 22=0.3300
CDF 23=0.3500
CDF 24=0.3590
CDF 25=0.3730
CDF 26=0.3830
CDF 27=0.3970
CDF 28=0.4070
CDF 29=0.4100
CDF 30=0.4210
CDF 31=0.4300
CDF 32=0.4420
CDF 33=0.4470
CDF 34=0.4530
CDF 35=0.4650
CDF 36=0.4810
CDF 37=0.4860
CDF 38=0.4970
CDF 39=0.5070
CDF 40=0.5150
CDF 41=0.5250
CDF 42=0.5400
CDF 43=0.5470
CDF 44=0.5540
CDF 45=0.5800
CDF 46=0.5880
CDF 47=0.6070
CDF 48=0.6280
CDF 49=0.6450
CDF 50=0.6670
CDF 51=0.6890
CDF 52=0.7100
CDF 53=0.7360
CDF 54=0.7560
CDF 55=0.7810
CDF 56=0.7990
CDF 57=0.8190
CDF 58=0.8370
CDF 59=0.8590
CDF 60=0.8810
CDF 61=1.0000



SEARCHER SPEED=12.0
 ASSUMED TARGET SPEED= 8.0
 TIME LATE= 4.0
 TOTAL SEARCH TIME= 96.00

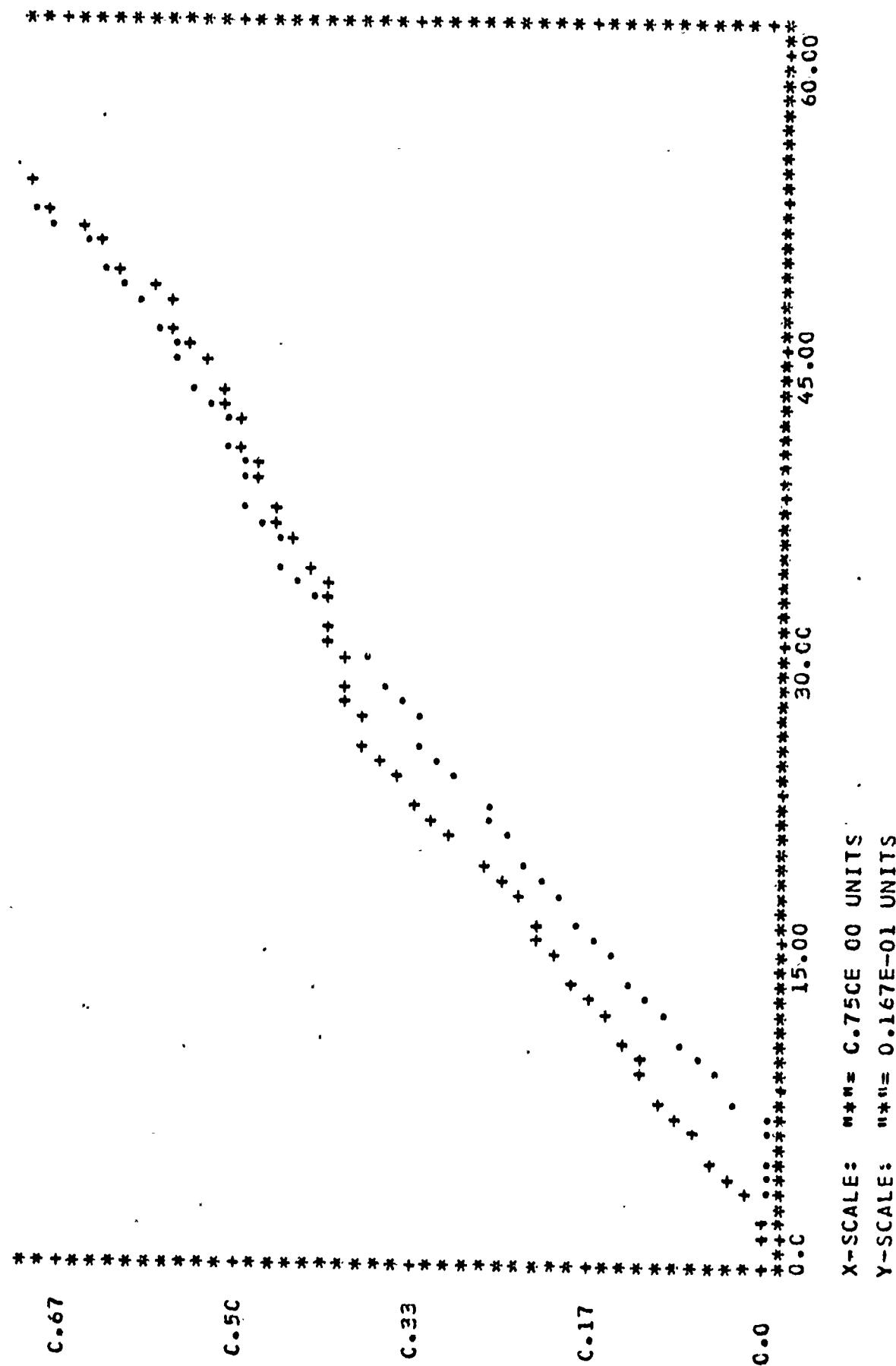
KCCFMAN
 SEARCH
 PLAN

ALTERNATE
 SEARCH
 PLAN

FACTOR= 1.0 MULTIPLIER= 2.00

CDF 1=C.0
 CDF 2=C.0
 CDF 3=C.0
 CDF 4=C.0
 CDF 5=C.0010
 CDF 6=C.000850
 CDF 7=C.000240
 CDF 8=C.000100
 CDF 9=C.000040
 CDF 10=C.000010
 CDF 11=C.000008
 CDF 12=C.000005
 CDF 13=C.000003
 CDF 14=C.000002
 CDF 15=C.000001
 CDF 16=C.000000
 CDF 17=C.000000
 CDF 18=C.000000
 CDF 19=C.000000
 CDF 20=C.000000
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 CDF 22=C.000000
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 CDF 54=C.000000
 CDF 55=C.000000
 CDF 56=C.000000
 CDF 57=C.000000
 CDF 58=C.000000
 CDF 59=C.000000
 CDF 60=C.000000
 CDF 61=1.0000

CDF 1=0.0
 CDF 2=0.0080
 CDF 3=0.0150
 CDF 4=0.0320
 CDF 5=0.0470
 CDF 6=0.0600
 CDF 7=0.0810
 CDF 8=0.1000
 CDF 9=0.1050
 CDF 10=0.1230
 CDF 11=0.1360
 CDF 12=0.1560
 CDF 13=0.1660
 CDF 14=0.1810
 CDF 15=0.1940
 CDF 16=0.2100
 CDF 17=0.2230
 CDF 18=0.2330
 CDF 19=0.2510
 CDF 20=0.2740
 CDF 21=0.2920
 CDF 22=0.3140
 CDF 23=0.3300
 CDF 24=0.3470
 CDF 25=0.3620
 CDF 26=0.3760
 CDF 27=0.3870
 CDF 28=0.3960
 CDF 29=0.3980
 CDF 30=0.4060
 CDF 31=0.4110
 CDF 32=0.4170
 CDF 33=0.4220
 CDF 34=0.4250
 CDF 35=0.4370
 CDF 36=0.4500
 CDF 37=0.4600
 CDF 38=0.4700
 CDF 39=0.4790
 CDF 40=0.4890
 CDF 41=0.4960
 CDF 42=0.5040
 CDF 43=0.5130
 CDF 44=0.5240
 CDF 45=0.5330
 CDF 46=0.5470
 CDF 47=0.5600
 CDF 48=0.5730
 CDF 49=0.5900
 CDF 50=0.6190
 CDF 51=0.6410
 CDF 52=0.6550
 CDF 53=0.6770
 CDF 54=0.6930
 CDF 55=0.7110
 CDF 56=0.7440
 CDF 57=0.7560
 CDF 58=0.7800
 CDF 59=0.8020
 CDF 60=0.8190
 CDF 61=1.0000



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SEARCHER SPEED=12.0
 ASSUMED TARGET SPEED= 8.0
 TIME LATE= 4.0
 TOTAL SEARCH TIME= 96.00

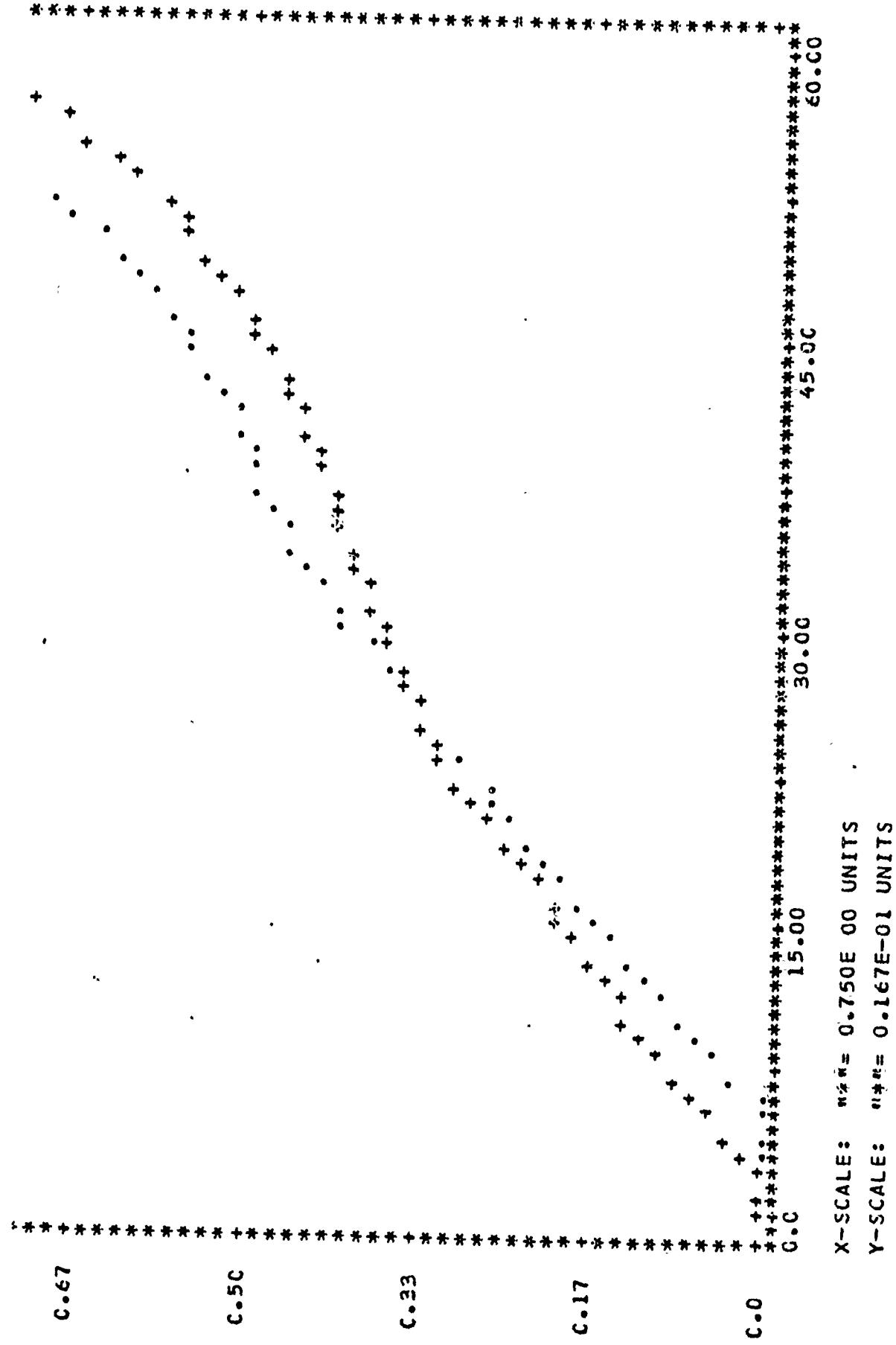
KCCPMAN
SEARCH
PLAN

ALTERNATE
SEARCH
PLAN

FACTOR= 1.1 MULTIPLIER= 2.00

CDF 1=C.0
CDF 2=C.0
CDF 3=C.0
CDF 4=C.0
CDF 5=C.0010
CDF 6=C.00300
CDF 7=C.00600
CDF 8=C.00250
CDF 9=C.0450
CDF 10=C.0670
CDF 11=C.0870
CDF 12=C.1050
CDF 13=C.1200
CDF 14=C.1380
CDF 15=C.1550
CDF 16=C.1690
CDF 17=C.1880
CDF 18=C.2020
CDF 19=C.2140
CDF 20=C.2260
CDF 21=C.2440
CDF 22=C.2590
CDF 23=C.2740
CDF 24=C.2920
CDF 25=C.3120
CDF 26=C.3270
CDF 27=C.3410
CDF 28=C.3560
CDF 29=C.3720
CDF 30=C.3910
CDF 31=C.4050
CDF 32=C.4240
CDF 33=C.4390
CDF 34=C.4480
CDF 35=C.4600
CDF 36=C.4730
CDF 37=C.4800
CDF 38=C.4920
CDF 39=C.5010
CDF 40=C.5080
CDF 41=C.5170
CDF 42=C.5220
CDF 43=C.5340
CDF 44=C.5480
CDF 45=C.5600
CDF 46=C.5680
CDF 47=C.5790
CDF 48=C.5930
CDF 49=C.6110
CDF 50=C.6320
CDF 51=C.6520
CDF 52=C.6760
CDF 53=C.7040
CDF 54=C.7270
CDF 55=C.7600
CDF 56=C.7940
CDF 57=C.8490
CDF 58=C.9100
CDF 59=C.9630
CDF 60=C.9920
CDF 61=1.0000

CDF 1=0.0
CDF 2=0.0020
CDF 3=0.0070
CDF 4=0.0140
CDF 5=0.0240
CDF 6=0.0540
CDF 7=0.0700
CDF 8=0.0880
CDF 9=0.0990
CDF 10=0.1130
CDF 11=0.1250
CDF 12=0.1370
CDF 13=0.1500
CDF 14=0.1630
CDF 15=0.1850
CDF 16=0.1960
CDF 17=0.2060
CDF 18=0.2170
CDF 19=0.2350
CDF 20=0.2470
CDF 21=0.2670
CDF 22=0.2780
CDF 23=0.2970
CDF 24=0.3100
CDF 25=0.3230
CDF 26=0.3300
CDF 27=0.3390
CDF 28=0.3490
CDF 29=0.3570
CDF 30=0.3660
CDF 31=0.3750
CDF 32=0.3820
CDF 33=0.3900
CDF 34=0.3980
CDF 35=0.4060
CDF 36=0.4120
CDF 37=0.4140
CDF 38=0.4170
CDF 39=0.4280
CDF 40=0.4380
CDF 41=0.4460
CDF 42=0.4550
CDF 43=0.4620
CDF 44=0.4700
CDF 45=0.4840
CDF 46=0.4950
CDF 47=0.5030
CDF 48=0.5230
CDF 49=0.5300
CDF 50=0.5470
CDF 51=0.5650
CDF 52=0.5750
CDF 53=0.5880
CDF 54=0.6170
CDF 55=0.6370
CDF 56=0.6620
CDF 57=0.6860
CDF 58=0.7110
CDF 59=0.7290
CDF 60=0.7590
CDF 61=1.0000



SEARCHER SPEED=12.0
 ASSUMED TARGET SPEED= 8.0
 TIME LATE= 4.0
 TOTAL SEARCH TIME= 96.00

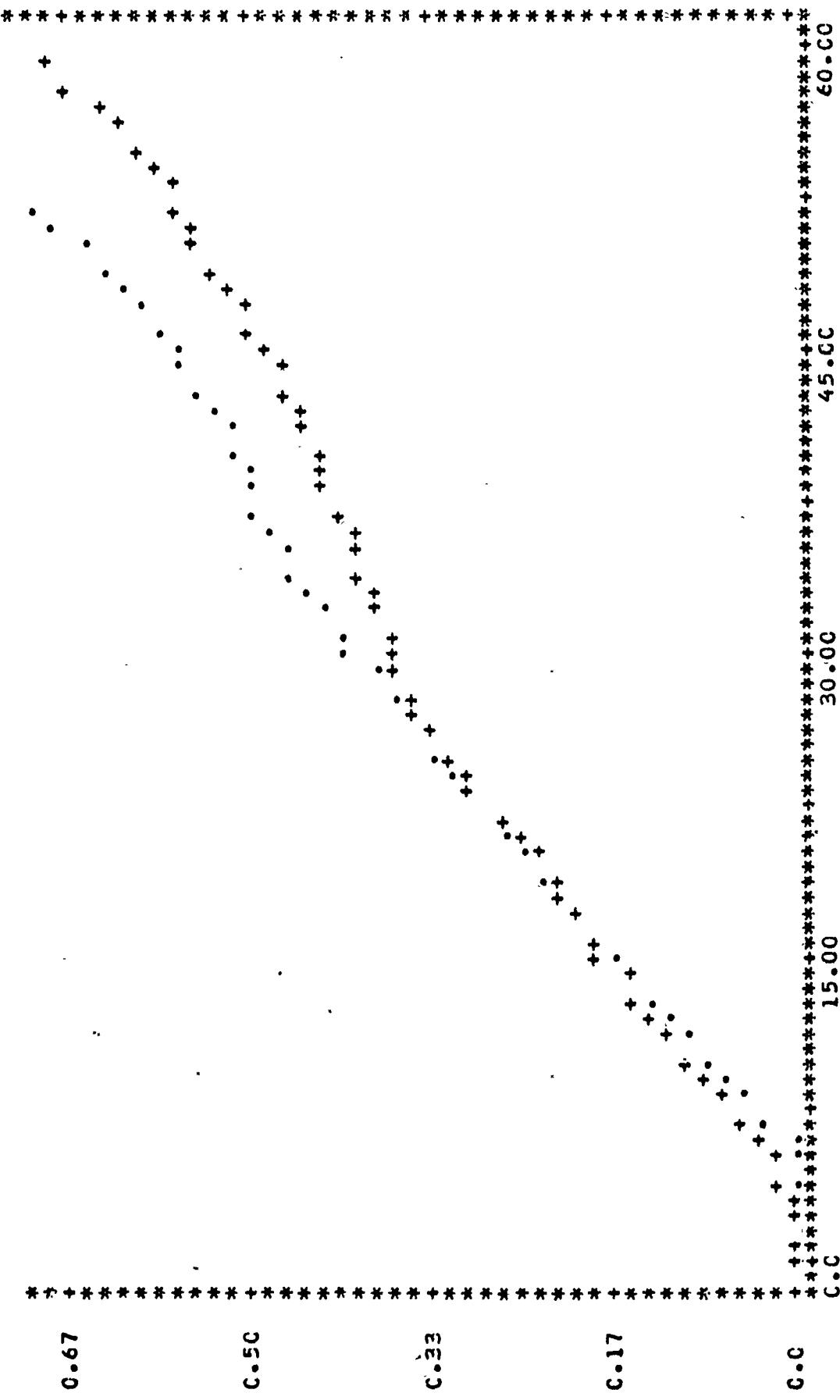
KCCPMAN
SEARCH
PLAN

ALTERNATE
SEARCH
PLAN

FACTOR= 1.2 MULTIPLIER= 2.00

CDF 1=C.0.C
CDF 2=C.0.C
CDF 3=C.0.O
CDF 4=C.0.C
CDF 5=C.0.010
CDF 6=C.0C3C
CDF 7=C.0C6C
CDF 8=C.025C
CDF 9=C.045C
CDF 10=C.067C
CDF 11=C.087C
CDF 12=C.105C
CDF 13=C.120C
CDF 14=C.138C
CDF 15=C.155C
CDF 16=C.165C
CDF 17=C.188C
CDF 18=C.202C
CDF 19=C.214C
CDF 20=C.229C
CDF 21=C.244C
CDF 22=C.255C
CDF 23=C.274C
CDF 24=C.292C
CDF 25=C.306C
CDF 26=C.320C
CDF 27=C.330C
CDF 28=C.343C
CDF 29=C.351C
CDF 30=C.362C
CDF 31=C.366C
CDF 32=C.371C
CDF 33=C.378C
CDF 34=C.386C
CDF 35=C.392C
CDF 36=C.397C
CDF 37=C.408C
CDF 38=C.418C
CDF 39=C.425C
CDF 40=C.432C
CDF 41=C.438C
CDF 42=C.449C
CDF 43=C.454C
CDF 44=C.462C
CDF 45=C.472C
CDF 46=C.480C
CDF 47=C.492C
CDF 48=C.500C
CDF 49=C.513C
CDF 50=C.533C
CDF 51=C.542C
CDF 52=C.555C
CDF 53=C.564C
CDF 54=C.574C
CDF 55=C.584C
CDF 56=C.601C
CDF 57=C.618C
CDF 58=C.639C
CDF 59=C.655C
CDF 60=C.680C
CDF 61=1.000C

CCF 1=0.0
CCF 2=0.0
CCF 3=0.0020
CCF 4=0.0040
CCF 5=0.0100
CCF 6=0.0180
CCF 7=0.0290
CCF 8=0.0480
CCF 9=0.0680
CCF 10=0.0860
CCF 11=0.0930
CCF 12=0.1130
CCF 13=0.1320
CCF 14=0.1470
CCF 15=0.1580
CCF 16=0.1750
CCF 17=0.1860
CCF 18=0.2000
CCF 19=0.2100
CCF 20=0.2210
CCF 21=0.2340
CCF 22=0.2470
CCF 23=0.2730
CCF 24=0.2920
CCF 25=0.3060
CCF 26=0.3200
CCF 27=0.3300
CCF 28=0.3430
CCF 29=0.3510
CCF 30=0.3620
CCF 31=0.3660
CCF 32=0.3710
CCF 33=0.3780
CCF 34=0.3860
CCF 35=0.3920
CCF 36=0.3970
CCF 37=0.4080
CCF 38=0.4180
CCF 39=0.4250
CCF 40=0.4320
CCF 41=0.4380
CCF 42=0.4490
CCF 43=0.4540
CCF 44=0.4620
CCF 45=0.4720
CCF 46=0.4800
CCF 47=0.4920
CCF 48=0.5000
CCF 49=0.5130
CCF 50=0.5330
CCF 51=0.5420
CCF 52=0.5550
CCF 53=0.5640
CCF 54=0.5740
CCF 55=0.5840
CCF 56=0.6010
CCF 57=0.6180
CCF 58=0.6390
CCF 59=0.6550
CCF 60=0.6800
CCF 61=1.0000



X-SCALE: $0.750E+00$ UNITS
Y-SCALE: $0.167E-01$ UNITS

SEARCHER SPEED=12.0
 ASSUMED TARGET SPEED= 8.0
 TIME LATE= 4.0
 TOTAL SEARCH TIME= 96.00

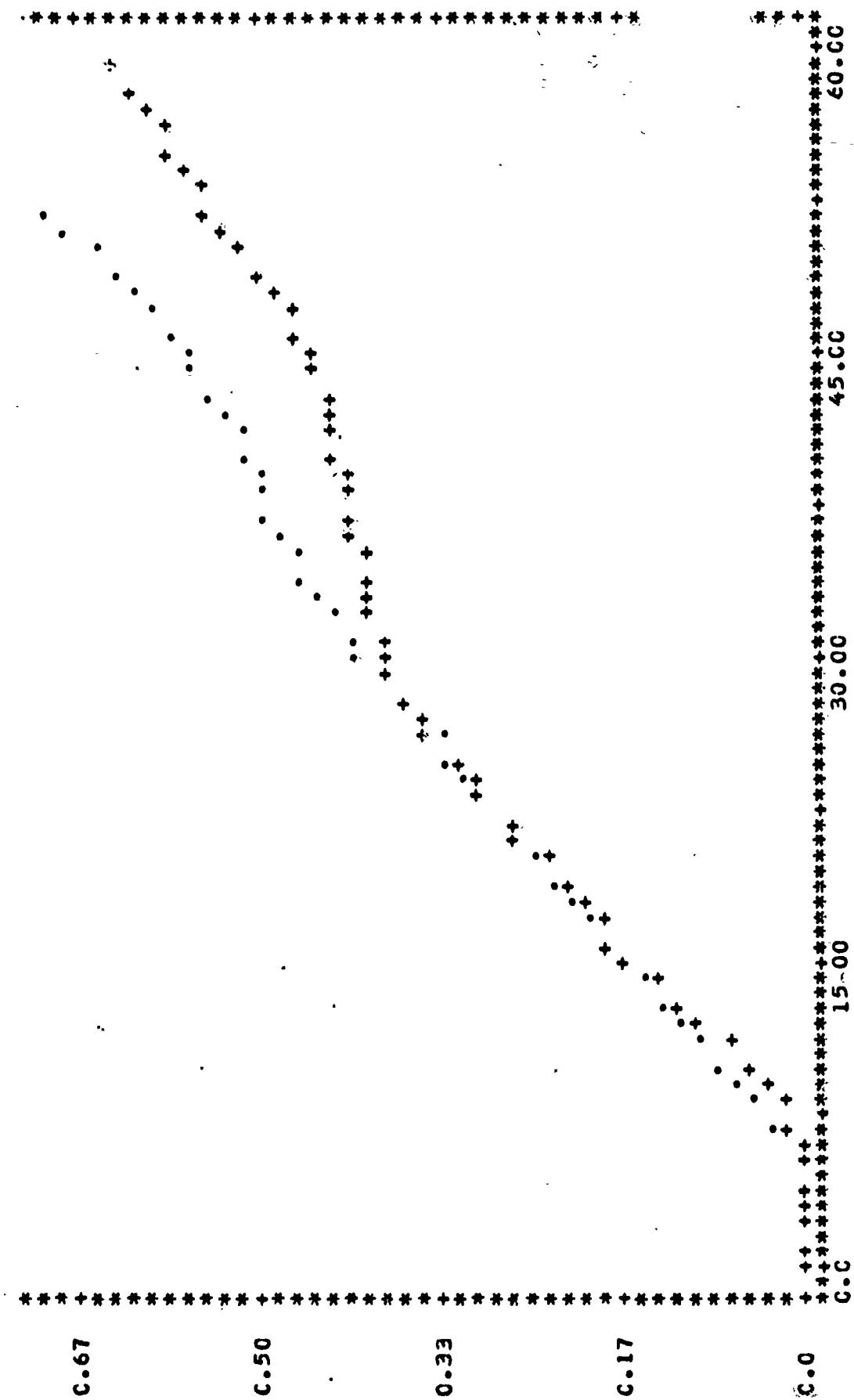
KCCPNAN
SEARCH
PLAN

ALTERNATE
SEARCH
PLAN

FACTOR= 1.3 MULTIPLIER= 2.00

CDF 1=C.0
CDF 2=C.0
CDF 3=C.0
CDF 4=C.0
CDF 5=C.0010
CDF 6=C.00300
CDF 7=C.00600
CDF 8=C.02500
CDF 9=C.04500
CDF 10=C.06700
CDF 11=C.08700
CDF 12=C.10500
CDF 13=C.12000
CDF 14=C.13800
CDF 15=C.15500
CDF 16=C.16900
CDF 17=C.18800
CDF 18=C.20200
CDF 19=C.21400
CDF 20=C.22900
CDF 21=C.24400
CDF 22=C.25900
CDF 23=C.27400
CDF 24=C.29200
CDF 25=C.31200
CDF 26=C.32700
CDF 27=C.34100
CDF 28=C.35600
CDF 29=C.37200
CDF 30=C.39100
CDF 31=C.40500
CDF 32=C.42400
CDF 33=C.43900
CDF 34=C.44800
CDF 35=C.46000
CDF 36=C.47300
CDF 37=C.48000
CDF 38=C.49200
CDF 39=C.50100
CDF 40=C.50600
CDF 41=C.51700
CDF 42=C.52200
CDF 43=C.52400
CDF 44=C.54800
CDF 45=C.56000
CDF 46=C.56800
CDF 47=C.57900
CDF 48=C.59300
CDF 49=C.61100
CDF 50=C.63000
CDF 51=C.65200
CDF 52=C.67600
CDF 53=C.70400
CDF 54=C.72700
CDF 55=C.76000
CDF 56=C.79400
CDF 57=C.84900
CDF 58=C.91000
CDF 59=C.96300
CDF 60=C.99200
CDF 61=1.00000

CDF 1=0.0
CDF 2=0.0
CDF 3=0.0
CDF 4=0.0
CDF 5=0.0
CDF 6=0.0020
CDF 7=0.0060
CDF 8=0.0150
CDF 9=0.0240
CDF 10=0.0300
CDF 11=0.0420
CDF 12=0.0690
CDF 13=0.0970
CDF 14=0.1120
CDF 15=0.1400
CDF 16=0.1610
CDF 17=0.1760
CDF 18=0.1950
CDF 19=0.1960
CDF 20=0.2140
CDF 21=0.2310
CDF 22=0.2590
CDF 23=0.2710
CDF 24=0.2920
CDF 25=0.3070
CDF 26=0.3220
CDF 27=0.3420
CDF 28=0.3530
CDF 29=0.3670
CDF 30=0.3760
CDF 31=0.3820
CDF 32=0.3860
CDF 33=0.3960
CDF 34=0.4000
CDF 35=0.4010
CDF 36=0.4040
CDF 37=0.4110
CDF 38=0.4180
CDF 39=0.4210
CDF 40=0.4230
CDF 41=0.4270
CDF 42=0.4280
CDF 43=0.4340
CDF 44=0.4400
CDF 45=0.4490
CDF 46=0.4570
CDF 47=0.4650
CDF 48=0.4730
CDF 49=0.4850
CDF 50=0.4990
CDF 51=0.5150
CDF 52=0.5280
CDF 53=0.5420
CDF 54=0.5560
CDF 55=0.5690
CDF 56=0.5760
CDF 57=0.5890
CDF 58=0.5940
CDF 59=0.6180
CDF 60=0.6330
CDF 61=1.0000



X-SCALE = 0.750E 00 UNITS
Y-SCALE = 0.167E-01 UNITS

SEARCHER SPEED=12.0
 ASSUMED TARGET SPEED= 8.0
 TIME LATE= 4.0
 TOTAL SEARCH TIME= 96.00

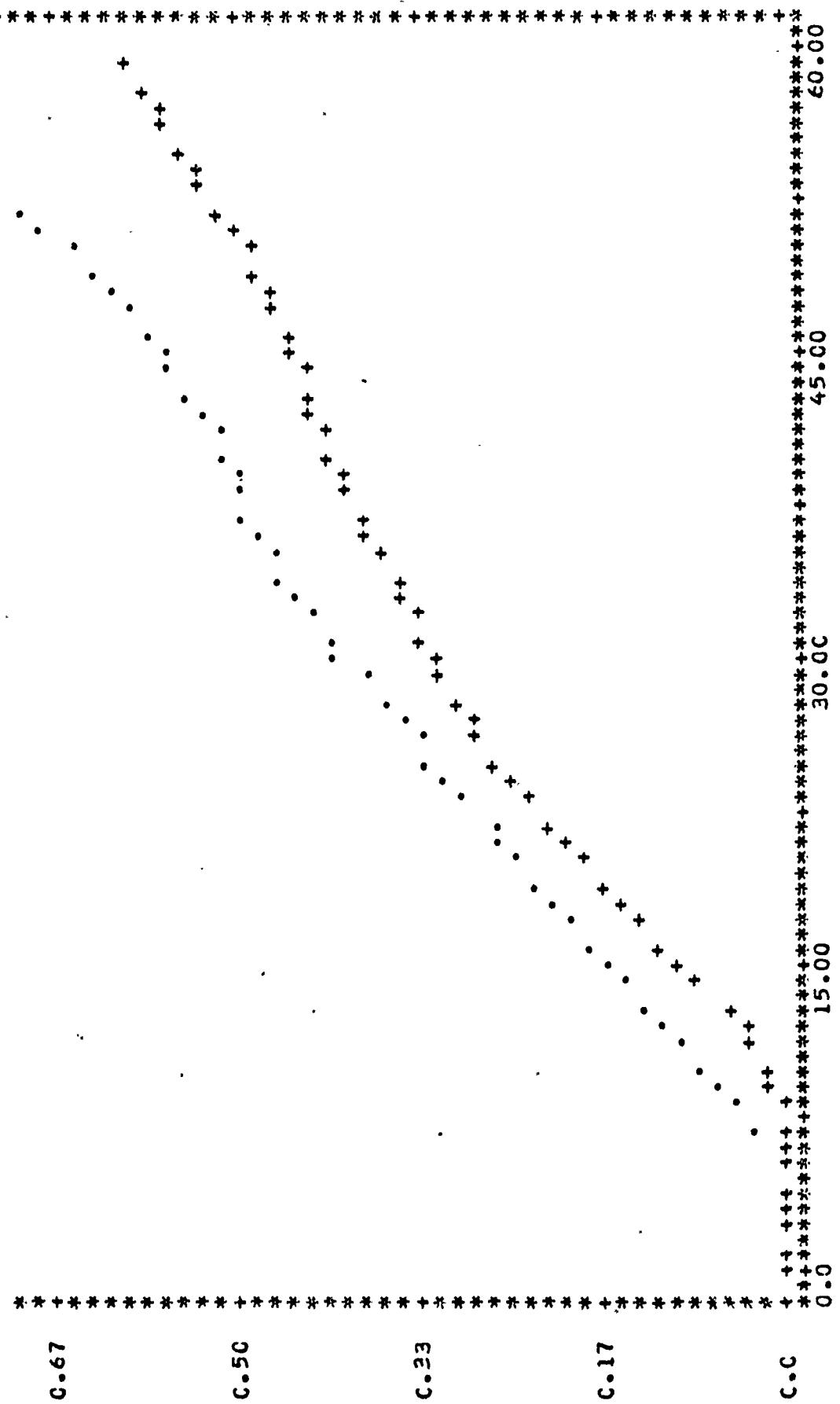
KCCFMAN
SEARCH
PLAN

ALTERNATE
SEARCH
PLAN

FACTOR= 1.4 MULTIPLIER= 2.00

CDF 1=0.0
CDF 2=0.0
CDF 3=0.0
CDF 4=0.0
CDF 5=C.0010
CDF 6=C.0030
CDF 7=C.0060
CDF 8=C.0250
CDF 9=C.0450
CDF 10=C.0670
CDF 11=C.0870
CDF 12=C.1050
CDF 13=C.1200
CDF 14=C.1380
CDF 15=C.1550
CDF 16=C.1690
CDF 17=C.1880
CDF 18=C.2020
CDF 19=C.2140
CDF 20=C.2290
CDF 21=C.2440
CDF 22=C.2590
CDF 23=C.2740
CDF 24=C.2920
CDF 25=C.3120
CDF 26=C.3270
CDF 27=C.3410
CDF 28=C.3560
CDF 29=C.3720
CDF 30=C.3910
CDF 31=C.4090
CDF 32=C.4240
CDF 33=C.4390
CDF 34=C.4480
CDF 35=C.4600
CDF 36=C.4730
CDF 37=C.4800
CDF 38=C.4920
CDF 39=C.5010
CDF 40=C.5060
CDF 41=C.5170
CDF 42=C.5220
CDF 43=C.5340
CDF 44=C.5480
CDF 45=C.5600
CDF 46=C.5680
CDF 47=C.5790
CDF 48=C.5930
CDF 49=C.6110
CDF 50=C.6300
CDF 51=C.6520
CDF 52=C.6760
CDF 53=C.7040
CDF 54=C.7270
CDF 55=C.7600
CDF 56=C.7940
CDF 57=C.8490
CDF 58=C.9100
CDF 59=C.9630
CDF 60=C.9920
CDF 61=1.0000

CDF 1=0.0
CDF 2=0.0
CDF 3=0.0
CDF 4=0.0
CDF 5=0.0
CDF 6=0.0
CDF 7=0.0
CDF 8=0.0
CDF 9=0.0010
CDF 10=0.0140
CDF 11=0.0230
CDF 12=0.0290
CDF 13=0.0410
CDF 14=0.0560
CDF 15=0.0800
CDF 16=0.1040
CDF 17=0.1220
CDF 18=0.1560
CDF 19=0.1550
CDF 20=0.1690
CDF 21=0.1840
CDF 22=0.1960
CDF 23=0.2150
CDF 24=0.2340
CDF 25=0.2530
CDF 26=0.2650
CDF 27=0.2780
CDF 28=0.2880
CDF 29=0.3010
CDF 30=0.3110
CDF 31=0.3230
CDF 32=0.3330
CDF 33=0.3410
CDF 34=0.3460
CDF 35=0.3580
CDF 36=0.3670
CDF 37=0.3760
CDF 38=0.3870
CDF 39=0.3950
CDF 40=0.4060
CDF 41=0.4140
CDF 42=0.4190
CDF 43=0.4250
CDF 44=0.4320
CDF 45=0.4400
CDF 46=0.4460
CDF 47=0.4530
CDF 48=0.4600
CDF 49=0.4710
CDF 50=0.4790
CDF 51=0.4860
CDF 52=0.5050
CDF 53=0.5150
CDF 54=0.5270
CDF 55=0.5390
CDF 56=0.5490
CDF 57=0.5620
CDF 58=0.5710
CDF 59=0.5880
CDF 60=0.6020
CDF 61=1.0000



C.67

C.50

C.23

C.C

C.17

SEARCHER SPEED=12.0
 ASSUMED TARGET SPEED= 8.0
 TIME LATE= 4.0
 TOTAL SEARCH TIME= 96.00

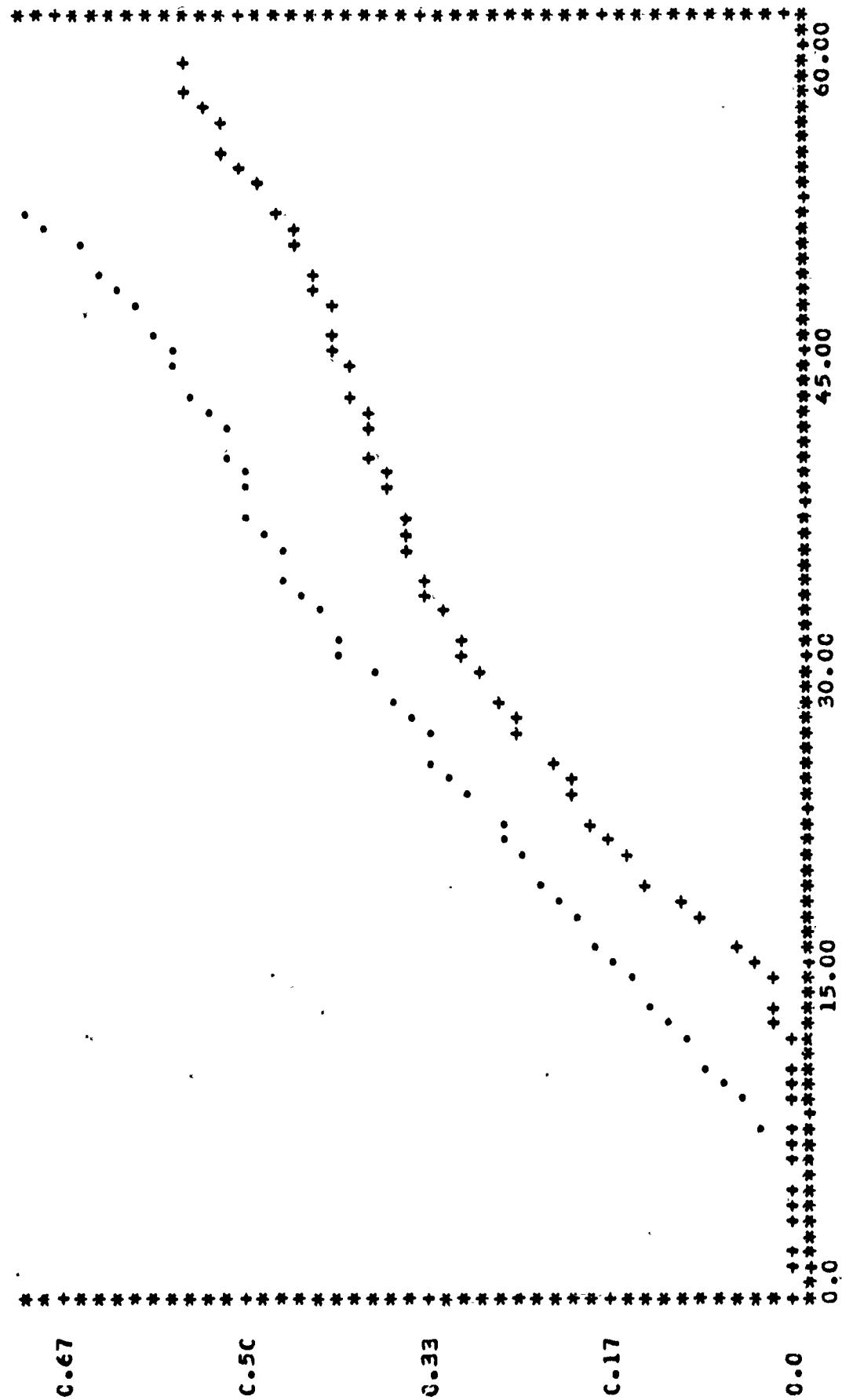
KCCPMAN
SEARCH
PLAN

ALTERNATE
SEARCH
PLAN

FACTOR= 1.5 MULTIPLIER= 2.00

CCF 1	= C . 0
CCF 2	= C . 0
CCF 3	= C . 0
CCF 4	= C . 0
CCF 5	= C . 0010
CCF 6	= C . 0030
CCF 7	= C . 0060
CCF 8	= C . 0250
CCF 9	= C . 0450
CCF 10	= C . 0670
CCF 11	= C . 0870
CCF 12	= C . 1050
CCF 13	= C . 1200
CCF 14	= C . 1380
CCF 15	= C . 1550
CCF 16	= C . 1690
CCF 17	= C . 1880
CCF 18	= C . 2020
CCF 19	= C . 2140
CCF 20	= C . 2290
CCF 21	= C . 2440
CCF 22	= C . 2590
CCF 23	= C . 2740
CCF 24	= C . 2920
CCF 25	= C . 3120
CCF 26	= C . 3270
CCF 27	= C . 3410
CCF 28	= C . 3560
CCF 29	= C . 3720
CCF 30	= C . 3910
CCF 31	= C . 4090
CCF 32	= C . 4240
CCF 33	= C . 4390
CCF 34	= C . 4480
CCF 35	= C . 4600
CCF 36	= C . 4730
CCF 37	= C . 4800
CCF 38	= C . 4520
CCF 39	= C . 5010
CCF 40	= C . 5060
CCF 41	= C . 5170
CCF 42	= C . 5220
CCF 43	= C . 5340
CCF 44	= C . 5480
CCF 45	= C . 5600
CCF 46	= C . 5680
CCF 47	= C . 5790
CCF 48	= C . 5930
CCF 49	= C . 6110
CCF 50	= C . 6300
CCF 51	= C . 6520
CCF 52	= C . 6760
CCF 53	= C . 7040
CCF 54	= C . 7270
CCF 55	= C . 7600
CCF 56	= C . 7940
CCF 57	= C . 8490
CCF 58	= C . 9100
CCF 59	= C . 9630
CCF 60	= C . 9920
CCF 61	= 1.0000

CDF 1	= 0 . 0
CDF 2	= 0 . 0
CDF 3	= 0 . 0
CDF 4	= 0 . 0
CDF 5	= 0 . 0
CDF 6	= 0 . 0
CDF 7	= 0 . 0
CDF 8	= 0 . 0
CDF 9	= 0 . 0
CDF 10	= 0 . 0010
CDF 11	= 0 . 0010
CDF 12	= 0 . 0040
CDF 13	= 0 . 0100
CDF 14	= 0 . 0170
CDF 15	= 0 . 0230
CDF 16	= 0 . 0350
CDF 17	= 0 . 0510
CDF 18	= 0 . 0770
CDF 19	= 0 . 1040
CDF 20	= 0 . 1310
CDF 21	= 0 . 1460
CDF 22	= 0 . 1610
CDF 23	= 0 . 1770
CDF 24	= 0 . 1930
CDF 25	= 0 . 2050
CDF 26	= 0 . 2230
CDF 27	= 0 . 2440
CDF 28	= 0 . 2580
CDF 29	= 0 . 2710
CDF 30	= 0 . 2880
CDF 31	= 0 . 2970
CDF 32	= 0 . 3060
CDF 33	= 0 . 3120
CDF 34	= 0 . 3270
CDF 35	= 0 . 3360
CDF 36	= 0 . 3430
CDF 37	= 0 . 3480
CDF 38	= 0 . 3530
CDF 39	= 0 . 3640
CDF 40	= 0 . 3710
CDF 41	= 0 . 3790
CDF 42	= 0 . 3820
CDF 43	= 0 . 3870
CDF 44	= 0 . 3950
CDF 45	= 0 . 4020
CDF 46	= 0 . 4110
CDF 47	= 0 . 4190
CDF 48	= 0 . 4250
CDF 49	= 0 . 4320
CDF 50	= 0 . 4410
CDF 51	= 0 . 4490
CDF 52	= 0 . 4570
CDF 53	= 0 . 4650
CDF 54	= 0 . 4800
CDF 55	= 0 . 4990
CDF 56	= 0 . 5130
CDF 57	= 0 . 5210
CDF 58	= 0 . 5310
CDF 59	= 0 . 5440
CDF 60	= 0 . 5530
CDF 61	= 1.0000



X-SCALE = 0.75CE 00 UNITS

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***** THIS PROGRAM CALCULATES ONE CIRCUIT OF THE KGCP MKV
***** SEARCH PLAN FOR VARIOUS COMBINATIONS OF TARGET SPEED
***** SEARCHER SPEED AND TIME LATE. IT OUTPUTS A PRINTED
***** LISTING OF THE PROBABILITY OF TARGET DETECTION AS A
***** FUNCTION OF ACTUAL SONAR RANGE. THIS DATA IS ALSO
***** PRESENTED IN A GRAPHICAL FORMAT
*****
***** DIMENSION R(5),SL(4),TCC(5),XC(5),YC(5),A1(4),
1X(6),NTALLY(60),CDF(6),RSC(9)
1DATA NTALLY/60*0/,A2(4),A3(4),A4(4),
NRUNS=0
NTRUN=3000
STE=4.0
SULCT=359.0 * 0.01745329
LLCCT=0.0
BOXES=60.0
RANGE=60.0
DX=BOXES/RANGE
X(1)=0.0
DC(1)=0.0
I=1-1
X(I)=FLCAT(I)
1C CCNTINUE
      C RANDOM NUMBER GENERATOR
      KR=16807
      IRS=27456385
      IC=IRS*KR
      CCNTINUE
      CULST=STE
      LLST=STE
      T=3.0
      4C CCNTINUE
      SC SC=8.0
      IF(STE.GE. 50) GO TO 70
      100 CCNTINUE
      P=0.0
      SIGMA=2.0
      RS=10.0
      CRXC=0.0
      ORYC=0.0
      C COMPUTE PARAMETERS NECESSARY TO OBTAIN A SEARCH PLAN
      CC

```

```

E=RS/0.69315
S=C*(SO+STE)/(SO-STE)
RATIO=SIGMA/STE
IF(RATIO>TL) GO TO 200
R(1)=S/(SM**2+1.0)
GC TO 220
220 R(1)=0.8*STE*TL
A=(SO*S)/(SO-STF)

C CALCULATE R(2) THRU R(5)

      R(2)=SH * R(1)
      R(3)=SH * R(2)
      R(4)=SH * R(3)
      R(5)=SH * R(4) +A

C COMPUTE SEARCH LEG LENGTHS

      SL(1)=SH * R(1)
      SL(2)=SH * SL(1) +R(1)
      SL(3)=SL(2)*SH
      SL(4)=SH*SL(3)+A

C COMPUTE TOTAL TIME SEARCHING

      TSL=SL(1)+SL(2)+SL(3)+SL(4)
      TST=TSL/SG

C CALCULATE X AND Y COORDINATES OF THE SEARCH LEGS

      XC(1)=0*XC-R(1)
      XC(2)=XC(1)
      XC(3)=YC(1)+SL(1)
      XC(4)=YC(2)+SL(2)
      XC(5)=YC(3)-SL(3)
      XC(6)=YC(4)-SL(4)

C CALCULATION OF TIMES AT WHICH SEARCHER REACHES SEARCH
LEG COORDINATES

      TCC(1)=TL+SL(1)/SO
      TCC(2)=TCC(2)+SL(2)/SO
      TCC(3)=TCC(3)+SL(3)/SO

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```

TCC(4)=TCC(3)+SL(3)/SO
TCC(5)=TCC(4)+SL(4)/SC
C DETERMINE INITIAL VALUES FOR SEARCH LEG ONE
A1(1)=XC(1)
A2(1)=0.0
A3(1)=YC(1)
A4(1)=SC
C DETERMINE INITIAL VALUES FOR SEARCH LEG TWO
A1(2)=XC(2).
A2(2)=SO
A3(2)=YC(2)
A4(2)=0.0
C DETERMINE INITIAL VALUES FOR SEARCH LEG THREE
A1(3)=XC(3)
A2(3)=0.0
A3(3)=YC(3)
A4(3)=-SO
C DETERMINE INITIAL VALUES FOR SEARCH LEG FOUR
A1(4)=XC(4)
A2(4)=-SO
A3(4)=YC(4)
A4(4)=0.0
C SELECT TGT COURSE UNIFORMLY BETWEEN UPPER AND LOWER LIMIT
153 CONTINUE
IC=IC*KR
RN2=0.5+FLOAT(IC) * 2.328306E-10
CT=RNI*(ULCT-LLCT) +LLCT
C GENERATE DIRECTION AND DISTANCE OF DATUM UNCERTAINTY
LC=IC*KR
RN2=0.5+FLOAT(IC) * 2.328306E-10
DDU=RN2*2.0*3.14159
Z=C*0
DC=160 J=1,12
IC=IC*KR
Z=Z+FLCAT(IC) * 2.328306E-10
155 CONTINUE

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```

R2=SIGMA *Z2+FLOAT(MU)
DSCU=ABS(RN3)

C GENERATE TARGET SPEED UNIFORMLY BETWEEN UPPER AND LOWER LIMITS
IC=IC*KR
RN4=0.5+FUGAT((IC)*2.328306E-10
STA=RN4*(ULST-LLST)+LLST

C CALCULATE TARGET X AND Y VELOCITY COMPONENTS
25C VTX=SIA*SINC(CT)
VTY=STA*COS(CT)

C CALCULATE INITIAL TARGET X AND Y COORDINATES
TGTXC=DRXC + DSDU * COS(DDU)
TGTYC=DRC + DSDU * SIN(DDU)

C DETERMINE CANDIDATES FOR MINIMUM FROM SEARCH LEG INTERVAL
DC 300 K=1,4
KK=(K)+1
TINERT=-((A1(K)-VTX)**2+(A4(K)-VTY)**2)
1 IF(TINERT<=0.01 GO TO 310
IF(TINERT>LT TCC(K)) GO TO 310
SX= A1(K)+A2(K)*TINERT
SYC=A3(K)+A4(K)*TINERT
VTX=VTX*TINERT+TGTXC
VTY=VTY*TINERT+TGTYC
RSQ(K)=(SXC-TXC)**2+(SYC-TYC)**2
GOTO 200
310 RSC(K)=9.9999E+10

C CONTINUE
33C CONTINUE

C DETERMINE END POINT CANDIDATES FOR MINIMUM
DC 400 K=5,9
K1=(K)-4
TLINE=TCC(K1)
SXC=XCC(K1)
SYC=YCC(K1)
VTXC=TGTXC+VTX*TIME
VTYC=TGYC+VTY*TIME
RSQ(K)=(SXC-TXC)**2+(SYC-TYC)**2
4 CC CONTINUE

```

```

CCCCC DETERMINE THE CLOSEST POINT OF APPROXIMATION FOR THIS ITERATION
      RSQM=RSQ(1)
      DC=200 K=2
      RMIN=A MIN(RSQM,RSQ(K) )
      RSQM=RMIN
      CCNTINUE
      RCPA=SQR(T(RSQM))

CCCC TALLY CPA RANGES INTO BCXES
      IF(FCPA.GE.59.0) GO TO 610
      LR=DX*RCPA+1.0
      NTALLY(LR)=NTALLY(LR)+1
      GO TO 150
      610 NTALLY(60)=NTALLY(60)+1
      C INCREMENT NUMBER OF RUNS
      1150 NRUNS=NRUNS +1

CCCC TEST TO SEE IF DESIRED NUMBER OF RUNS OBTAINED
      IF(NRUNS.EQ. NTRUN) GO TO 1200
      GO TO 153
      CCNTINUE
      1200
      C RESET ITERATION COUNTER TO ZERO
      ARUNS=0

CCCC COMPUTE TOTAL NUMBER OF TALLIES
      NTSUM=0.0
      DC 650 L=1,60
      NTSUM=NTSUM + NTALLY(L)
      CCNTINUE
      650
      C COMPUTE INDIVIDUAL RANGE PROBABILITIES AND THE
      CCUMULATIVE INDIVIDUAL RANGE PROBABILITIES
      CCF(1)=C.0
      SCMP=0.0
      DC 670 M=1,60
      MN=M+1

```


END

```

***** THIS PROGRAM COMPARES THE KOOPMAN SEARCH PLAN FOR A
***** PARTICULAR TARGET SPEED AGAINST VARIOUS ALTERNATE SEARCH PLANS.
***** AGAINST TIME AVAILABLE IS SET AT A FIXED VALUE. EACH
***** SEARCH PLAN IS RUN FOR THIS FIXED AMOUNT OF TIME. ITS
***** OUTPUT IS A LISTING OF THE PROBABILITY OF TARGET DETECTION AS A FUNCTION OF THE ACTUAL SONAR RANGE. THIS
***** INFORMATION IS ALSO PRESENTED IN A GRAPHICAL FORMAT
***** DIMENSION X(61), R(5), SLK(20), YCK(21), XCK(20),
1A4(20), TCK(21), RSQ(150), XCO(101), YCO(101), E1(100),
2E4(100), TSLQ(100), TCO(101), CDF(61), CDF2(61), NTALLY(60),
DATA NTALLY/60#0/

```

INPUT CONSTANTS FOR THE MODEL

```

SITE=8.0
TL=4.0
SC=12.0
TRLIMIT=96.0
NRUNS=0
NTRUN=3000
ULCT=359.0*0.0174539
LLCT=0.0
NU=0.0
SIGMA=2.0
SRX=0.0
SRY=0.0
RS=10.0
BXES=60.0
RANGE=60.0
CX=BOXES/RANGE
XC(1)=0.0
CC(10)=0.0
I1=1-1
X(I1)=FLCAT(I1)
1C CCNTINUE

```

RANDOM NUMBER GENERATOR

```

KR=16807
IRS=27456385
IC=KR*IRS

```

SET UPPER AND LOWER TARGET SPEED LIMITS

```

C      C COMPUTE PARAMETERS NECESSARY FOR A KOOPMAN SEARCH
C
C      LLST=STE
C
C      E=RS/0.69315*(SIGMA)
C      S=C*(SO+STE)/(SO-STE)
C      SRATIO=SIGMA/SITE
C      TFRATE=1.0/(SRATIO*SLK) GO TO 200
C      R(1)=S/(SM#*2+1.C)
C      GC TO 220
C      R(1)=0.8*STE*TL
C      200   R(1)= (SO*S)/(SO-STE)
C      220   A=(SO*S)/(SO-STE)

C      COMPUTE KOOPMAN SEARCH LEG LENGTHS FOR FIVE CIRCUITS
C
C      SLK(1)=SM*R(1)
C      SLK(2)=SM*SLK(1)+R(1)
C      SLK(3)=SM*SLK(2)
C      SLK(4)=SM*SLK(3)+A
C      SLK(5)=SM*SLK(4)
C      SLK(6)=SM*SLK(5)+A
C      SLK(7)=SM*SLK(6)
C      SLK(8)=SM*SLK(7)-2.0*A
C      SLK(9)=SM*SLK(8)
C      SLK(10)=SM*SLK(9)-2.0*A
C      SLK(11)=SM*SLK(10)
C      SLK(12)=SM*SLK(11)+3.0*A
C      SLK(13)=SM*SLK(12)
C      SLK(14)=SM*SLK(13)+3.0*A
C      SLK(15)=SM*SLK(14)
C      SLK(16)=SM*SLK(15)-4.0*A
C      SLK(17)=SM*SLK(16)
C      SLK(18)=SM*SLK(17)-4.0*A
C      SLK(19)=SM*SLK(18)
C      SLK(20)=SM*SLK(19)+5.0*A

C      CALCULATE X AND Y COORDINATES OF THE SEARCH LEGS
C
C      XCK(1)=CRYC-R(1)
C      YCK(1)=CRYC
C      XCK(2)=XCK(1)
C      YCK(2)=YCK(1)+SLK(2)
C      XCK(3)=XCK(2)
C      YCK(3)=YCK(2)
C      XCK(4)=XCK(3)

```

```

YCK(4)=YCK(3)-SLK(3)
CC 230 KK=1,4
KKC=4*(KK)
KK1=4*(KK)+1
KK2=4*(KK)+2
KK3=4*(KK)+3
KK4=4*(KK)+4
XCK(KK1)=YCK(KK0)
XCK(KK2)=YCK(KK1)+ SLK(KK1)
XCK(KK3)=YCK(KK2)+ SLK(KK2)
XCK(KK4)=YCK(KK3)- SLK(KK3)
230 CCNTINUE
XCK(21)=XCK(20)-SLK(20)
YCK(21)=YCK(20)

C DETERMINE INITIAL VALUES FOR SEARCH LEG ONE
C
310 LV=1
A1(LV)=XCK(LV)
A2(LV)=C0
A3(LV)=YCK(-V)
A4(LV)=SO
LV=LV+4
IF(LV.EC.21) GO TO 315
CCNTINUE
315
C DETERMINE INITIAL VALUES FOR SEARCH LEG TWO
C
320 LV=2
A1(LV)=XCK(LV)
A2(LV)=SO
A3(LV)=YCK(LV)
A4(LV)=C0
LV=LV+4
IF(LV.EC.22) GO TO 325
CCNTINUE
325
C DETERMINE INITIAL VALUES FOR SEARCH LEG THREE
C
330 LV=3
A1(LV)=XCK(LV)

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A3(LV)=YCK(LV).
A4(LV)=-SO
LV=LV+4
IF(LV.EC.23) GO TO 335
GC TU 330
CONTINUE
335 DETERMINE INITIAL VALUES FOR SEARCH LEG FCUR
      LV=4
      A1(LV)=XCK(LV)
      A2(LV)=-SO
      A3(LV)=-SO
      A4(LV)=YCK(LV)
      A5(LV)=C.O
      LV=LV+4
      IF(LV.EC.24) GO TO 350
      GC TO 340
350 CONTINUE

C       CALCULATION OF TIMES AT WHICH SEARCHER REACHES SEARCH
C       LEG COORDINATES
CCCCC
      TCK(I)=TL
      SLSLH=TL
      DCL=260 II=2,21
      ASL=(II-1)
      SLSUM=SLSUM + SLK(ASL)/SG
      TCK(II)=SLSUM
      IF(TCK(II).GT.TLIMIT) GC TO 370
      36C CONTINUE
      ATC=ASL+1
      37C CONTINUE

C       SELECT TGT COURSE UNIFORMLY BETWEEN UPPER AND LOWER LIMIT
      372 CONTINUE
      IC=IC*KR
      RAI=0.5 *FLCAT(IC) *2.328306E-10
      CT=RNI*(ULCT-LLCT) +LLCT
      CCCCC GENERATE DIRECTION AND DISTANCE CF DATUM UNCERTAINTY
      IC=IC*KR
      RAI=0.5 *FLCAT(IC) *2.328306E-10
      CCU=RN2*2.C23.14159
      375 Z=1,20
      EC 380 J=1,12

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IC=IC*KR
Z=Z+FLCAT(IC) *2.32E306E-10
CCNTINUE
RN3=SIN(A)*Z +FLCAT(MU)
DSCU=ABS(RN3)

C GENERATE TARGET SPEED UNIFORMLY BETWEEN UPPER AND LOWER LIMITS

IC=IC*KR
RN4=0.5*FLCAT(IC)*2.328306E-10
STA=RN4*(ULST-LLST)+LLST

C CALCULATE INITIAL TARGET X AND Y COORDINATES

TETXC=GRXC + DSDU * COS(DDU)
TETYC=ORYC + DSDU * SIN(DDU)

C CALCULATE TARGET X AND Y VELOCITY COMPONENTS

385 VTX=STA*SIN(CT)
VTY=STA*COS(CT)

C DETERMINE CANDIDATES FOR MINIMUM FROM SEARCH LEG INTERVAL

CC 400 K=1, NSL
KK=(K)+1
TIMEKT=-((A1(K)-TGTXC)*(A2(K)-VTX)+(A3(K)-TETYC)*(A4(K)-VTY))/
1.((A2(K)-VTX)*#2+(A4(K)-VTY)*#2)

IF(TIMER*TLE<0.0) GO TO 410
IF(TIMER*GT*TCK(KK)) GO TO 410
IF(TIMER*LT*TCK(KK)) GO TO 410
IF(TIMER*GT*TLIMIT) GO TO 410
SX=A1(K)+A2(K)*TINERT
SYC=A3(K)+A4(K)*TINERT
TXC=VTX*TIMER*TGTXC
TYC=VTY*TIMER*TGTYC
RSQ(K)=(SXC-TXC)**2+(SYC-TYC)**2
GO TO 400
410 RSC(K)=\$9999E+10
CCNTINUE

C DETERMINE END POINT CANDIDATES FOR MINIMUM

KPLUS1=NSL+1
KPLUS2=2*NSL+1
DC 450 K=KPLUS1, KPLUS2
K1=(K)-NSL
TIME=TCK(K1)

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    IF (TIME .GE. TLIMIT) GO TO 460
    SYC=YC(K1)+VTX*TIME
    TYC=TGTYC+VTY*TIME
    RSC(K)=((SXC-TYC)**2+(SYC-TYC)**2)
45C CCNTINUE
46C CCNTINUE
47C KPLUS2=(K)-1

C DETERMINE THE CLOSEST POINT OF APPROACH FOR THIS ITERATION
C
RSCM=RSC(1)
DC500 K=2 KPLUS2
RMIN=AMIN(RSQM,RSQ(K))
RSCY=RMIN
CCNTINUE
RCPA=SQRT(RSCM)
TALLY CPA RANGES INTO BOXES
C
IF (RCPA .GE. 59.0) GO TO 610
LR=D*DX*RCPA+1.0
NTALLY(LLR)=NTALLY(LR)+1
CTO 1150
61C NTALLY(EC)=NTALLY(EO)+1
C INCREMENT NUMBER OF RUNS
C
1150 NRUNS=NRUNS +1
C TEST TO SEE IF DESIRED NUMBER OF RUNS OBTAINED
C
IF (NRUNS .EQ. NTRUN) GO TO 1200
CTO 373
120C CCNTINUE
C RESET ITERATION COUNTER TO ZERO
C
ARUNS=0
C COMPUTE TOTAL NUMBER OF TALLIES
C
NTSUM=0.0
CTO 650 L=1:60
NTSUM=NTSUM + NTALLY(L)
65C CCNTINUE

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CCCCC COMPUTE INDIVIDUAL RANGE PROBABILITIES AND THE
CCCCC CCF(1)=0.0
CCCCC SUMP=0.0
CCCCC DC 670 N=1,60
CCCCC P=M+1
CCCCC PBOX=FLOAT(INTALLY(M))/FLOAT(NTSUM)
CCCCC SUMP=SUMP+PBOX
CCCCC CCF(M)=SUMP
CCCCC CONTINUE
67C

CCCCC RESET ALL TALLY BOX VALUES TO ZERO
CCCCC CC 680 I=1,60
CCCCC NTALLY(I)=0
CCCCC CONTINUE
68C

CCCCC COMPUTE PARAMETERS FOR THE ALTERNATE SEARCH PLAN
CCCCC CMULT=2.0
CCCCC FACTOR=C.8
CCCCC FACTOR=0.8
CCCCC CONTINUE
CCCCC XEIST=FACTOR*STE*TL
69C

CCCCC COMPUTE ALTERNATE SEARCH LEG LENGTHS
CCCCC CC 700 MM=1,24
CCCCC CMULT=0.91*MM
CCCCC SLC(MM)=CMULT*XDIST
CCCCC CONTINUE
70C

CCCCC CALCULATE X AND Y COORDINATES OF THE SEARCH LEGS
CCCCC XCC(1)=CRXC-XDIST
CCCCC YCC(1)=CRYC
CCCCC XCC(2)=XCO(1)+SL0(1)
CCCCC YCC(2)=YCO(1)+SL0(1)
CCCCC XCC(3)=XCO(2)+SL0(2)
CCCCC YCC(3)=YCO(2)
CCCCC XCC(4)=XCO(3)-SL0(3)
CCCCC YCC(4)=YCO(3)-SL0(3)
CCCCC DC 710 NN=1,5

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N C = 4 * ( N N ) + 1
N N 1 = 4 * ( N N ) + 2
N N 2 = 4 * ( N N ) + 3
N N 3 = 4 * ( N N ) + 4
N N 4 = X C C ( N N ) - S L C ( N N )
N N 1 = Y C C ( N N ) + S L C ( N N )
N N 2 = Y C C ( N N ) + S L C ( N N )
N N 3 = Y C C ( N N ) + S L C ( N N )
N N 4 = Y C C ( N N ) + S L C ( N N )
Y C C ( N N 4 ) = Y C C ( N N 3 ) - Y C C ( N N 3 )
71C C C T I N U E
Y C C ( 2 5 ) = X C C ( 2 4 ) - S L C ( 2 4 )
C C D E T E R M I N E I N I T I A L V A L U E S F O R S E A R C H L E G C N E
C C 8 1 C L V = 1
B 1 ( L V ) = X C C ( L V )
B 2 ( L V ) = 0 . 0
B 3 ( L V ) = Y C C ( L V )
B 4 ( L V ) = S O
L V = L V + 4
I F ( L V . E C . 2 5 ) G O T O 8 1 5
G C T O 8 1 0
C C T I N U E
8 1 5 C C D E T E R M I N E I N I T I A L V A L U E S F O R S E A R C H L E G T h C
C C 8 2 C L V = 2
B 1 ( L V ) = X C C ( L V )
B 2 ( L V ) = S C
B 3 ( L V ) = Y C C ( L V )
B 4 ( L V ) = 0 . 0
L V = L V + 4
I F ( L V . E C . 2 6 ) G O T O 8 2 5
G C T O 8 2 0
C C T I N U E
8 2 5 C C D E T E R M I N E I N I T I A L V A L U E S F O R S E A R C H L E G T H R E E
C C 8 3 C L V = 3
B 1 ( L V ) = X C C ( L V )
B 2 ( L V ) = C C
B 3 ( L V ) = Y C C ( L V )
B 4 ( L V ) = - S C

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```

LV=LV+4
IF(LV.EC.27) GO TO 835
835 CCNTINUE
C DETERMINE INITIAL VALUES FOR SEARCH LEG FCUR
84C LV=4
E1(LV)=XCO(LV)
E2(LV)=-SO
E3(LV)=YC0(LV)
E4(LV)=C.0
LV=LV+4
IF(LV.EC.28) GO TO 850
85C CCNTINUE
C CALCULATION OF TIMES AT WHICH SEARCHER REACHES SEARCH
86C TCC(1)=TL
SLC(SUM)=TL
DC(860)=2.25
ASLC=(1)-1
SLC(SUM)=SLC(SUM)+ SLCL(SLC)/SC
TCC(1)=SLC(SUM)
IF(TCO(1).GT. TLIMIT ) GO TO 870
86C CCNTINUE
87C CCNTINUE
C SELECT TGT CURSE UNIFORMLY BETWEEN UPPER AND LOWER LIMIT
88C CCNTINUE
IC=IC*KR
RN1=0.5+FLOAT(IC)*2.328306E-1C
CT=RN1*(ULCT-LLCT)+LLCT
C GENERATE DIRECTION AND DISTANCE OF DATUM UNCERTAINTY
IC=IC*KR
RA2=0.5+FLOAT(IC)*2.328306E-1C
DEL=RN2*2.0*3.14159*2.328306E-1C
89C Z=C*0
DC*900 J=1,12
IC=IC*KR
Z=Z+FLCAT(IC)*2.328306E-1C
RN2=SIGMA*Z+FLCAT(MU)
DSDU=ABS(RN3)

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900 CCNTINUE
C   GENERATE TARGET SPEED UNIFORMLY BETWEEN UPPER AND LOWER LIMITS
C
IC=IC*KR
RN4=0.5+FUCAT(IC)*2.328206E-10
STA=RN4*(ULST-LLST)+LLST

C   CALCULATE TARGET X AND Y VELOCITY COMPONENTS
C
91C VTX=STA*SIN(CT)
VTY=STA*CGS(CT)

C   CALCULATE INITIAL TARGET X AND Y COORDINATES
C
TGTXC=DXC + CCS(DDU),
TGTYC=DYC + DSDU * SIN(DDU)
C
C   DETERMINE CANDIDATES FOR MINIMUM FROM SEARCH LEG INTERVAL
C
DC 1000 K=1,NSLO
KK=(K)+1
TIME=-(B1(K)-TGTXC)*(B2(K)-VTX)+(B3(K)-TGTYC)*(B4(K)-VTY)//  

1((B2(K)-VTX)*2+(B4(K)-VTY)*2)
IF(TIMERLT•0.0) GO TO 1010
IF(TIMERLT•TCC(K)) GO TO 1010
IF(TIMERLT•LT•TCC(K)) GO TO 1010
IF(TIMERLT•GT•TCLIMIT) GO TO 1010
SX=A1(K)+A2(K)*TINERT
SYC=A3(K)+A4(K)*TINERT
TXC=VTX* TINERT + TGTXC
TYC=(SYC-TXC)*2 +(SYC-TYC)**2
RSC((K))=(SXC-TXC)*2 +(SYC-TYC)**2
GO TO 1000
1010 RSC(K)=5.9999E+1.0
1020 CCNTINUE
C
C   DETERMINE END POINT CANDIDATES FOR MINIMUM
C
KPLUS3=NSLO+1
KPLUS4=2 * NSLO +1
DC 1020 K=KPLUS3 , KPLUS4
K1=(K)-NSLO
TIME=TC(C(K))
IF(TIME•GE•TLIMIT) GO TO 1030
SX=XC((K))
SYC=YCO((K))
TXC=TGTXC +VTX*TIME

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TYC=TGTYC + VTY * TIME
RSG(K)=(SXC-TYC)**2 +(SYC-TYC)**2
102C CCNTINUE
   GC TO 1340
1030 KFLUS4=(K)-1
104C CCNTINUE
C DETERMINE THE CLOSEST POINT OF APPROACH FOR THIS ITERATION
C RSCM=RSG(1)
DC 1050 K=2 KPLUS4
RFIN=INV(RSQM,RSG(K) )
RSCH=RMIN
CCNTINUE
RCFA=ISCRT(RSQM)
105C
C TALLY CFA RANGES INTO BOXES
IF(RCPA*GE.59.0) GC TO 1060
LR=DIX*RCPA+10
NTALLY(LR)=NTALLY(LR)+1
GC TO 1250
NTALLY(60)=NTALLY(60)+1
106C INCREMENT NUMBER OF RUNS
C 125C NRLNS=NRLNS+1
C TEST TO SEE IF DESIRED NUMBER OF RUNS OBTAINED
C IF(NRUNS .EQ. NTRUA) GO TO 1300
   GC TO 880
   CCNTINUE
130C
C RESET ITERATION COUNTER TO ZERO
NRUNS=0
C COMPUTE TOTAL NUMBER OF TALLIES
NTSUM=0.0
DC 1310 L=1,60
NTSUM=NTSUM+NTALLY(L)
1310 CCNTINUE
C COMPUTE INDIVIDUAL RANGE PROBABILITIES AND THE
C CUMULATIVE PROBABILITIES
CCCCC

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CCF2(1)=0.0
SLP=0.0
CC 1320 M=1,60
P=X+1
PEOX=FLOAT(INTALLY(P))/FLCAT(INTSUM)
SUMP=SUMP+FBOX
CCF2(MM)=SUMP
CONTINUE(6,9710)
971C FORMAT(6,9730)
973C FORMAT(6,9730)
1METERS,1KFORMAT(9740) SO,STE,T,L
1/20X,SEARCH, SPEED=0,F4.1,/20X, ASSUMED TARGET SPEED=0,F4.
1CALL PLCTP(X,CDF,6,1)
CALL PLCTP(X,CDF2,6,1)
WRITE(6,9700)SO,STE,T,L
1/20X,SEARCH, SPEED=0,F4.1,/20X, TIME LATE=0,F4.1,/25X,! TCTAL SEARCH TIME
2RGET SPEED=0,F4.1,/25X,! TIME LATE=0,F4.1,/25X,! ASSUMED TIME
3=F8.2,/ )
4WRITE(6,98C5)
5KFORMAT(10X,'KOOPMAN',14X,'ALTERNATE',/ ,10X,'SEARCH',15X,'SEARCH',/,/
2,10X,'PLAN',17X,'PLAN',/)
6KRITE(6,SBC6)FACTOR,CMULT
9806 FORMAT(3IX,FACTOR=0,F4.1,2X, MULTIPLIER=0,F6.2,/)
DC 1330 N=1,61
6KRITE(6,9810)N,CDF(N);N,CDF2(N)
9810 FORMAT(1IX,CDF,13,=0,F6.4,8X,CDF,13,=0,F6.4)
133C CONTINUE

C RESET ALL TALLY BOX VALUES TC ZERO
DC 1340 I=1,60
ATALLY(I)=0
134C CONTINUE

C SUBROUTINE TO VARY THE X DISTANCE
FACTCR=FACTOR+0.1
IF(FACTOR.GE.1.5) GO TO 1350
GC TO 6SC

C SUBROUTINE TO VARY THE MULTIPLIER
CMULT=CMULT+ 0.5*MULT
135C CONTINUE

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IF CANTINUE . 8.01 GC TO 1360
GC TO 685
CANTINUE
STCF
EAC
1360

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